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THE FOURTH INDIAN SCIENCE CONGRESS, BANGALORE, JANUARY 1917.

The Fourth Indian Science Congress was held in Bangalore on January 10th, 11th, 12th and 13th, 1917, under the presidency of Sir Alfred Bourne, K.C.I.E., D.Sc., F.R.S. The meeting was attended by about 270 members and some 70 papers were communicated, abstracts of which are given below.

The Patron of the Congress, H.H. the Maharajah of Mysore, G.C.S.I., was present at the opening meeting and welcomed the visitors in a felicitous speech.

Presidential Address.

By Sir Alfred Gibbs Bourne, *D.Sc., F.R.S., K.C.I.E.*

Your Highness,

My first duty is the very pleasant one of saying, on behalf of the members of this Congress, how much we value the honour Your Highness has done us in consenting to be our Patron and in coming here to preside at our opening meeting. Many of our members have come from distant parts of India and are paying their first visit to the State of Mysore; the interest of this visit is greatly enhanced by the pleasure of seeing Your Highness in person.

Ladies and Gentlemen,

Before going further may I say how greatly I appreciate the honour of my new position as President of this Congress, a most unexpected honour as it is now fifteen years since I was caught up by the great wheels of administration and had during that time very little leisure or energy to devote to scientific work. This is one reason among others why I cannot follow in the footsteps of my distinguished predecessor and offer you, as he did, an intellectual treat.

I had, at first, hoped it would be possible for me to attempt some review of the history of science in India; and though I have been compelled to give up that idea as impracticable, I should like to express my gratitude to Mr. K. V. Rangaswami Aiyengar of Trivandrum for the notes which he kindly compiled for me on the science handed down to us in Sanskrit literature. I make one quotation from these notes now; its bearing on my own remarks will be evident later. After pointing out that no scientific treatises in Sanskrit have come down which deal with the subject matter of any of the Physical Sciences in the direct modern manner, he says: "Even in such cases as those of Indian Astronomy and Mathematics, we find the purely scienti-

fic aim subordinated to the practical and the subjects treated of as incidental to the consideration of practical arts like Mensuration or Judicial Astrology." I am not quite clear as to what Judicial Astrology is, but we shall doubtless agree that it is not pure science.

I was particularly anxious that the Congress should meet in Bangalore in order to give its members the opportunity of becoming acquainted with the Indian Institute of Science, that they might see for themselves what has been so far the outcome of Mr. J. N. Tata's unique beneficent intention and what immense possibilities there are for the future, if others would follow his excellent example.

Unfortunately, the Institute itself is not a suitable place for the holding of our meetings owing to the lack of sufficient accommodation for visitors on the spot and the difficulties of transit to and fro. It is, however, an ill wind that blows no one any good, and as things are we have the pleasure of accepting the hospitality of His Highness' Government and of seeing at leisure the very excellent arrangements made in this so well termed go-ahead State for the teaching and practice of science.

This is the fourth meeting of this Congress, and I think you will all join me in congratulating those who have worked so hard to bring such a Congress into being. Although Dr. Simonsen of Madras and Mr. MacMahon of Lucknow are perhaps responsible for its conception, the Congress has hitherto found a complaisant foster-father in the old established Asiatic Society of Bengal, and it may become permanently established as a peripatetic form of activity of that Society. That Society began life under the auspices of Sir William Jones, and he wisely urged at its inaugural meeting that there should be no rules, and for a long time there were no rules and the Society flourished without them. There is, however, little doubt that he made what were virtually rules, although not so-called, as occasion required. A founder may do this but every Society that persists beyond the time of its founder finds the need for some rules however few and simple. This Congress has managed fairly well up to now without any, but one of the matters which will be brought before you at the present meeting will be the desirability of some simple constitution. We are indeed to have a discussion with regard to its future, and I venture in the first place to offer a few comments and suggestions bearing upon the Congress.

The body to which the Congress most nearly corresponds is the British Association for the Advancement of Science. Such an organization found its place in the Salomon's House of Bacon's fable wherein they had "Circuites or Visits of Divers Principall Citties of the Kingdome, wher, as it commeth to passe, wee doe publish such New Profitable Inventions, as wee thinke good."

Like the British Association we may, I think, safely say that we contemplate no interference with the ground occupied by other institutions.

The objects of the British Association were at the outset declared to be :—

"To give a stronger impulse and a more systematic direction to scientific enquiry,—
to promote the intercourse of those who cultivate science in different parts of the British Empire, with one another and with foreign philosophers,—
to obtain a more general attention to the objects of science, and a removal of any disadvantages of a public kind which impede its progress."

These have remained its avowed objects for 85 years.

To speak of the last of these first, it has not the force now which it had in the early part of last century. There may still be comparatively few "whose favoured steps the lamp of science through the jealous maze of nature guides," but there is no comparison between the amount of general attention the objects of science now receive and the state of things in 1831. So far as a general appreciation of science, its aims and methods was concerned, those days were not so very very far removed from the time when "chymistes were distillers of waters," or people who "turned"—or were supposed to turn—"everything into siluer," or perhaps in the East from the time when "the most eager search was the transmutation of metals and the elixir of immortal health." Indeed, within the year just closed a gentleman came to the Institute of Science to show us how to obtain gold from egg-shells, and not long ago I received a postal order of no small amount with a request that the value might be remitted in boxes of our best brain pills.

Science of some sort is now being very widely taught at all stages of education, and so far from its progress being impeded as used to be the case by disadvantages of a public kind, most Governments are more or less alive to the importance of devoting public funds in furtherance of scientific work and almost every Honours list now contains the names of men distinguished in science.

In this country the various Governments have made a very fair beginning in the matter of funds.

It is impossible and would be of little value for our purposes to estimate the amount devoted to scientific teaching in schools and colleges by the various Education Departments. I have, however, endeavoured, with the kind assistance of the Hon'ble Mr. Davidson and the Financial Department of the Government of Madras, to form some idea of the amount being spent upon original research and other higher scientific work throughout the country.

With the nature and essence of "research" I propose to offer a few observations later on, but it is not without interest to note at this point the connections in which the word occurs in the various budget estimates. The Government of India support a Forest *Research* Institute and College at Dehra Dun, and devote about 4 lakhs a year to it; they contribute 5 lakhs a year to the Indian *Research* Fund, about 5½ lakhs to the Agricultural *Research* Institute at Pusa, and a lakh to the Central *Research* Institute at Kasauli.

Some of the local Governments have entertained, or propose to entertain, what they call in the budget, Forest *Research* Officers. The Agricultural College in the Madras Presidency has, for part of its title, that of *Research* Institute. The Government of Bengal give *research* scholarships. The Punjab Government enter a small portion of their contribution to Government Colleges as *research* grant. In Burma a small sum is devoted to what are called Leprosy *researches*.

The budgets, however, provide for many other forms of scientific activity in connection with which the word research does not happen to have been used, such as:—further experimental work in connection with agriculture, bacteriological work as affecting man and animals, other investigations of a medical nature, and work relating to fisheries and other industries.

Further, various Governments support Museums in some of which, at any rate, scientific work is carried on, and our Institute here at Bangalore receives an annual grant of Rs. 87,500 from the Government of India who have promised, should any private individual be willing to subscribe, to provide a like amount so long as their total grant does not exceed Rs. 1,50,000.

Lastly, there are the various Imperial Surveys; in some of these the expenditure must, of course, be mainly debited to administrative work, but in the majority of them the funds do something towards the progress of science.

In all these ways and without taking the Surveys into account the annual expenditure from public funds on scientific work in British India is somewhere in the neighbourhood of Rs. 70—80 lakhs, that is to say, £500,000; and to this must, of course, be added large capital sums invested in buildings. I have the exact figures under each head but the difficulty comes when one endeavours to pick out the expenditure resulting in additions to scientific knowledge, and I have given the Government the benefit of the doubt in the majority of the doubtful cases.

This expenditure is supplemented to some extent by the more progressive of the Native States, including, I need hardly say, the State in which we have the pleasure to be at present.

Lastly, private sources have contributed but to a lamenta-

bly small extent. In this latter respect there have been a few striking exceptions, and perhaps the foremost of these was the projected gift of the late Mr. Tata to the carrying out of which by his sons our Institute owes its existence.

So far as Government contributions are concerned, I must leave it to others interested to make more exact calculations, particularly with a view to deciding what share of this expenditure is intended to make for progress in science and to institute comparisons with similar efforts in other countries. I cannot arrive at any total for expenditure in Great Britain on corresponding objects, but I note that, at the opening of the National Physical Laboratory in England in 1902, His Majesty the King, then Prince of Wales, expressed the belief that it was "almost the first instance of the State taking part in scientific research," and that the capital grant towards that laboratory was £13,000 (*viz.* under two lakhs), and that the annual allowance towards its maintenance was £4,000 (0·6 lakh in our budget terminology), while the only other sum mentioned by the recently appointed Advisory Council as a State contribution of any magnitude in the pre-war period of the present century, is an annual subsidy of £20,000 (since increased to £30,000) to the Imperial College of Science and Technology at South Kensington. I would ask you to compare these figures so far as they go, on the one hand with those I have just given for some individual institutions in India, and, on the other, with the amount that must have been contributed from private sources in England.

I do not ask you to make any odious comparison with what has been spent by any State in Central Europe but would remind you of a private benefaction in another continent of about 22 million dollars yielding an *annual* income of what amounts to over Rs. 30 lakhs in our currency.

I do not intend to dwell further on finance, nor need I linger over the other ways in which science has obtained recognition in recent years, but it is clear that much has been done not only to remove disadvantages of a public kind but actually to further the progress of science, since the Association we have taken as a model was founded. This Congress may now do its share.

With regard to the first object of the British Association, *viz.* to give a stronger impulse and a more systematic direction to scientific enquiry, I would ask this Congress to consider how it can secure this stronger impulse, and particularly, a more systematic direction.

It seems doubtful whether much will be done in this respect if the programme continues to be limited to an address from the President, a few public lectures; and for the rest, meetings in small sections for the reading of papers some of which, I gather from past proceedings, have been mere preliminary

notes, while others, although valuable contributions to science, are of immediate interest to very few.

I am not instituting any comparison, invidious or otherwise, in this respect with the British Association, but should like to point out that from its foundation onwards some of the most important work of that body is to be found in the "Reports on the State of Science." The Board of Scientific Advice in India has, it is true, for several years published an Annual Report, and in some subjects this gives a very fair idea of the progress during the year, but in others it is little more than an extract from some administration report, and there seems to be no attempt at co-ordination nor any endeavour to formulate desiderata.

In these days of increasing specialization great effort ought to be made by those working at one subject to get some notion of the progress in others. To make one or two suggestions, there might be some greater effort at combined meetings to deal with subjects in which all or most scientific men must take some interest; there might be permanent committees dealing with specific problems, and the President of each Section, if you must have Sections, might endeavour to review recent work in his subject. This latter is indeed frequently done, but as these addresses are usually all delivered at the same hour they are for the most part listened to only by those who best know beforehand what that work has been.

The other object which the British Association sets before itself, *viz.* to promote the intercourse of those who cultivate science in different parts of the British Empire with one another and with foreign philosophers, has always seemed to me, even taken alone, to justify the annual meeting; but here again the object would be more fully attained, were something arranged other than that the agriculturalists should shut themselves up in one room, the chemists in another, while the devotees of Natural Science segregate themselves in various ways and pay very scant attention even to one another. I can quite sympathise with the botanist failing to appreciate the beauty of a paper "On a Cubic Surface referred to a Pentad of Co-tangential Points," or the chemist being somewhat bored by a disquisition "On the Aberrant Form of the Sacrum connected with Naegele's Obliquely Contracted Pelvis," but is an Association or Congress with its rare opportunity of meeting a number of fellow-workers in science, albeit in other branches, a suitable occasion for such papers?

Should not some attempt be made throughout the meeting to deal with subjects intelligible to all students of science alike? There must be something in the complaint recently made by Prof. Armstrong that a science nowadays may develop a special language threatening to estrange the users altogether from common knowledge and sympathy, and some

of us fully appreciate the demand he quotes "that chemists should talk common sense in the vulgar tongue.

Should not such meetings as this be almost entirely devoted to the bringing together all the time of all the scientists present?

To quote the hitherto unborn words of the memorandum to be presented by my Council to the Industries Commission, "the isolation hitherto experienced by many scientific workers in India has been one of the chief reasons of the comparatively disappointing results."

Now if you will bear with me a little longer, I propose to revert to the question of research.

I have already drawn your attention to the frequent use of the term "research" in the Government budgets of the day. Look only a few years back and you will hardly find it in these documents. I have not been at any pains to measure the increase of frequency in the general use of the word but it is certain that it is now being continually brought before a public few of whom concerned themselves much with the matter in the very recent past.

Research is now alluded to as a perfectly simple operation, one even hears of men being "taught to research"; newspapers speak of it in the lightest manner, whereas, in even my student days, it was spoken of with almost bated breath as indicating something to which only the best of us could look forward, something which few of us were ever likely to carry on with any hope of success. How well I remember my own first piece of original work and the months I spent in trying to ascertain the structure of an organ little more than just visible to the naked eye and the excitement of trying to unravel its extreme complexity. My impression is that the term was at that time used almost entirely in connection with the pure science, but even in this respect it is now quite a common thing for a candidate for a higher degree in science to be expected to present a thesis based upon some original research, and there is a Professor in this country who, so I have been told, expects and helps each of his students to "turn out a research," to use a now common expression, every month. This may or may not be true. If true, it bespeaks considerable energy; how far it makes for progress authorities in the subject alone can say—at any rate it may serve as an example of how things have changed.

Then again instead of there being one or two isolated cases of Institutions professedly devoted to research such Institutions are now quite common. Some of these I have already alluded to, including that which is perhaps the most ambitious of all—The Carnegie Institution of Washington, founded by Andrew Carnegie "to encourage in the broadest and most liberal manner

investigation, research and discovery, and the application of knowledge to the improvement of mankind."

Perhaps the most striking and modern example of the use of the term has been the name given to the recently appointed Committee of the Privy Council—a Committee for Scientific and Industrial Research. This has still more recently become a separate Department of State and bids fair to influence profoundly the position of research. I have based some of my remarks upon the instructive report lately issued by the Advisory Council of that Committee.

As this is a Science Congress there are probably few present to whom this will not be the merest commonplace, but there seem to be many people in this and in other countries who have not yet fully realized that the word "research" is now in use in ways that differ greatly from one another. Almost all investigation is now spoken of as research. This is doubtless verbally correct; but the motive directing the investigation and the spirit in which it is carried out vary, and it seems desirable to emphasize the variations.

The Oxford Dictionary defines a researcher as "one who devotes himself to scientific or literary research (especially as contrasted, with one whose time is chiefly occupied in teaching or remunerative work)." The word "research" is now however very widely used in connection with remunerative work, that is to say, remunerative in a pecuniary sense.

The Advisory Council to which I have just referred quote the managing director of a manufacturing firm who stated that he had no interest in research which did not produce results within a year; it is evident that he meant results favourably affecting his own pocket.

Dr. Mees, the Director of the Research Laboratories of the Eastman Kodak Company, no doubt takes a wider view. His interesting paper has been published in *Nature*, but I take the following from the Advisory Council's report :—

"In this paper Dr. Mees points out that three grades of laboratory are needed by every manufacturer who wishes to get the best results from the application of science to his business. First he needs the ordinary routine or works laboratory for controlling the quality of raw materials, finished products and processes. Next he should have what Dr. Mees calls an industrial laboratory or, as it might perhaps be described, an efficiency laboratory where improvements in products and in processes tending to lessen cost of production and to introduce new products on the market are worked out. Valuable as this type of work is, it does not go to the root of things; the results it can give are strictly limited.

Fundamental developments in the whole subject in which a firm is interested require something very different from the

usual works laboratory. In every case where the effect of research work has been very marked, that work has been directed not towards the superficial processes of industry but towards the fundamental and underlying theory of the subject. The function of the third type of laboratory—the true research laboratory—is to formulate this underlying theory.

This kind of research work involves, Dr. Mees tells us, a laboratory very different from the usual works laboratory, and also investigations of a different type from those employed in a purely industrial laboratory. It means a large, elaborately equipped, and heavily staffed laboratory engaged largely on work which, for many years, will be unremunerative and which, for a considerable time after its foundation, will obtain no results at all which can be applied by the manufacturer. The shortest period in which any considerable results can be expected is five years, while results so considerable as to affect the whole industry cannot be looked for in less than ten years' consecutive work."

You will observe that even Dr. Mees' highest form of research that carried on in the true research laboratory as he calls it, is to be conducted with a view to remunerative results although these may be deferred for five or even ten years!

I would ask you to contrast this attitude with that indicated by Sir Ray Lankester in a lecture delivered at the meeting of the British Association in Sheffield. Lankester pointed out how different from "the eager practical spirit of the inventor who gains large pecuniary rewards" was "the devoted searching spirit of science which heedless of pecuniary rewards ever faces nature with a single purpose to ascertain the causes of things." "Invention," he said, "follows the footsteps of science at a distance. She is utterly devoid of that thriftless yearning after knowledge, that passionate desire to know the truth, which causes the unceasing advance of her guide and benefactress."

It is probably impossible to find a classification of research work devoid of considerable overlapping and in many cases the motives are undoubtedly mixed, but it seems possible to recognize three classes :—that carried on with the single purpose of ascertaining the truth in regard to the causes of things, that which has for its immediate object a specific utilitarian purpose but still without any expectation whatever of a pecuniarily remunerative result, and research with the avowed object of making money out of it sooner or later.

The first and second classes would come under the head of scientific research in the sense in which the term is used by the Privy Council, while the third class is industrial research; but what I want to emphasize is the fact that the first class alone is research in pure science, while the second and third classes are both research in applied science, that is science put to

practical use; practical as distinguished from abstract or theoretical.

Huxley said that what people call applied science is nothing but the application of pure science to particular problems. The Advisory Council say that this no doubt is so; there are not two different kinds of science, at the same time they realize that they have to deal with the practical business world in whose eyes a real distinction seems to exist between pure science and applied science. There are, however, men in the business world who see more clearly. An American manufacturer pointed out only the other day that "there are no sharp lines to separate pure from applied, scientific from practical, useful from useless. If one attempts to divide past research in such a manner he finds that time entirely rubs out the lines of demarcation."

It is interesting to note in passing that the word applied is being increasingly used in connection with specific branches of science. I have been unable to trace the history of such usage. The term Applied Mathematics must have considerable antiquity. There have, for many years, been chairs of Applied Mechanics, Applied Physics, and Technical Chemistry, but I have failed to find any early use of the term Applied Chemistry. Some branches of science have an applied side with a special title, such as Economic Botany, others are in their very nature wholly applied, such as Agriculture and Medicine.

But whatever terms have been used, the application of scientific knowledge for the good of mankind is as old as that knowledge itself, and one may safely say that the majority of those who have attempted this application have not been swayed by any pecuniary motive. The scientific agriculturist is not in most cases the person into whose pockets comes the money secured by the use of better methods. Medical science in all its branches is, as I have just said, applied science and although the doctor may earn his living by means of fees, medical research is not undertaken from pecuniary motives. It has been for the most part the application to a particular problem of the scientific knowledge of the day, and there has, of course, been no such application with a more noble purpose. Still it is not pure science and there have often been medical men who have left further application to others while they have reverted to purely scientific problems.

Sir Francis Bacon in the fable already quoted seems to have had in mind pure science on the one hand and applied science on the other:—

"Wee have Three that try New Experiments such as themselves thinke good. These wee call Pioners or Miners.

* * *

Wee have Three that bend themselves, Looking into the Experiments of their Fellowes, and cast about how to draw

out of them Things of Use, and Practise for Man's life and Knowledge.

These wee call Dowry-men or Benefactours."

* * *

Observe who are the Benefactours, and in the use of this term we all doubtless most cordially agree; personally I would not have it supposed for one moment that I am belittling research even if undertaken from pecuniary motives, or would say one word to detract from its importance. All I maintain is that pure science must remain upon a pedestal and no utilitarain work can replace it.

Dr. Mees may talk of going to the root of things and of the fundamental and underlying theory of a subject in connection with his industrial research, but all this is, for the most part, mere superstructure based on pure scientific research.

What utilitarian research would have discovered the fundamental facts in regard to electricity or have led to the framing of the atomic theory? Who can say how many profound truths await discovery because some utilitarian who happened upon a glimmering of them did not think it worth while to pause and investigate the apparently irrelevant? In like case your "Pioner or Miner" eager to ascertain the causes of all things would have asked no better lot than to follow up the faintly marked trail wheresoever it might lead, perchance in the end to the elucidation of some great truth susceptible of an application which might completely revolutionize the very subject upon which the utilitarian had been at work.

How much research has been undertaken by the student of pure science which he would have frankly admitted to be apparently useless! How much patient work and loving care have been bestowed upon investigations seemingly impossible of application to any of the specific problems of the day! Upon research of this kind no utilitarian would have been at all likely to embark, yet sooner or later such research has either proved capable of direct application or, and this has more often been the case, has unexpectedly formed a cornerstone, or occupied a more humble but still useful position, in building up some far-reaching generalization capable of being seized upon at once by the worker at applied science, thus in turn perhaps stimulating further scientific research.

It has been said that "even the brilliant experiments of Davy did not suffice to give any very great impetus towards further work at the subject until Ronalds constructed an electric telegraph, and in this and other ways pure electrical science received enormus impulses by the commercial applications of electricity." Thus according to Sir Frederick Bramwell "the applications of science and discoveries in pure science have acted and re-acted the one upon the other." No one can deny the existence of such action and reaction, but nevertheless it

remains true that each one of the modern practical applications of science, from wireless telegraphy to antitoxins, "had its foundations in purely scientific work, and was not the result of deliberate intention to make something of service to humanity." You will, I think, find evidence of this in the work from which I quote:—Professor Gregory's "Discovery; or the Spirit and Service of Science."

The immediate recognition of the value of applied work implied in the term "Dowry-men or Benefactours" does not, of course, trouble those with the "thriftless yearning": they have faith that sooner or later their work must fit in towards some useful purpose. We have heard of mathematicians who drink the toast "Here's to Pure Mathematics and may they never be of any use to anybody", but even they know that Mathematics rule and govern a great variety of subjects. Most students of pure science believe, to use weightier words than mine, that "you cannot get the science you desire for utilitarian ends by going straight for it. You must treat science with profound honour and respect and let her go on her own way. Then she will give you rich fruit; if you try to cripple and force and direct her to your own immediate ends she dries up and becomes a mere hag." Had there not been in the past men imbued with this spirit, there would have been no scientific knowledge to apply to any particular class of problem and any widely successful effort to wean the earnest student of pure science from his single purpose for any utilitarian end and above all by means of pecuniary reward must spell disaster for the distant future, and may hamper progress long ere that; but I cannot believe that a time will ever now come when there will not be many whose passionate desire to know the truth will rule them to the end.

This being so, it behoves even us devotees of pure science to do all we can to train and assist the race of "Dowry-men and Benefactours," and this is why I so strongly advocate the giving over of the Institute of Science to work of an applied character. We shall rejoice over any one in whom is born the passionate desire; but we must face the fact that men are wanted, and that in very large numbers, who will help the manufacturer, in the words of the Advisory Council, to overcome the difficulties that cross his path from day to day. The training of such men is indeed of the utmost importance if we are to emerge from the cloud that at present hangs over so many of our industries. A time is coming, we all devoutly hope that it may come soon, when things may return to their normal courses, but this cannot be until many years after this war is over. Then men of science all the world over can continue to pile up reserves in the way of knowledge, and we know that the *best* will remain "Pioners and Miners." Now our greater need by far is for the "Dowry-men or Benefactours";

there are ample balances upon which to draw, balances inherited from the " Pioners or Miners " who have gone before.

I have spoken of the cloud that hangs over industries, but one cannot forget that even this is as nothing when the whole sky is overcast when young, middle-aged and old alike, men of science as well as others, are sacrificing everything, forsaking what have hitherto been their ideals, giving their very lives, for the sake of what they hold to be a righteous cause.

We, too, are doing the duty allotted to us and, precluded from more active help, must take what comfort we can from Milton's words:— 'They also serve who only stand and wait."

My chief duty, as your President, is now over.

I fear I may have very partially succeeded in putting before you my own somewhat conflicting thoughts but it seems to me that a new danger of misconception in regard to science may loom large in the near future,—pure science may be almost submerged for a time by a wave of utilitarianism and it will require concerted and sustained effort to make people see things in their proper proportions. The motive of the utilitarian is so obviously unimpeachable ; the student of pure science may be, in the words of the Preacher, casting his bread upon the waters whence it may return only after many days. On the one hand is the crying need for active help, on the other is the conviction as to what is the ideal. I do no more than ask you, as citizens of the Empire and as students of science, to reflect upon these matters. Each must follow the dictates of his own conscience—" to thine own self be true ; thou canst not then be false to any man."

ABSTRACT OF PAPERS COMMUNICATED TO THE CONGRESS.

Section of Agriculture.

President.—MR. J. MACKENNA, *M.A., I.C.S., Agricultural Adviser to the Government of India and Director of the Pusa Agricultural Research Institute.*

The Agricultural Development of North-West India (Summary).[1] —*By* ALBERT HOWARD AND GABRIELLE L. C. HOWARD.

I. INTRODUCTION.

The development of the agriculture of North-West India is largely a question of the conquest of an alluvial desert by means of irrigation. There are only two defects to consider as far as the soil itself is concerned—want of organic matter and a tendency towards the accumulation of alkali salts These shortcomings, however, are small matters compared with the want of moisture.

[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

That water is the limiting factor in the agricultural production of North-West India is generally recognized. The continuous development of the work of the Irrigation Department is the outward and visible sign that the State is dealing with one of the greatest problems in Indian agriculture in a practical manner. The supply of irrigation water is, however, only the first stage in irrigation. Equally important is the discovery of the best use of this water and how we can extract from each unit its utmost duty. The provision of water is the work of the engineer. The discovery of the best method of using it is the work of the Agricultural Department.

The present position of irrigation in North-West India is this. Government has provided a magnificent system of canals which protect the country from famine and which increase its production. The people, however, do not know how to use this water to advantage and are making all kinds of mistakes in irrigation practice and are doing injury to the country. They have yet to realize the evils which follow from over-watering alluvial soils.

The waste of water is not the only defect in agricultural practice in the North-West. The necessity of increasing the supply of organic matter in desert soils is often lost sight of and insufficient use is made of the nitrogen collecting leguminous crops. The object of this paper is to suggest a means by which the fertility of the soil in this region can be increased and by which the present supplies of irrigation water can be made to go much further.

II. The Place of Leguminous Crops in Desert Agriculture.

The obvious method of increasing and maintaining the amount of organic matter in the soil is by means of green-manuring. In desert agriculture this is, however, a counsel of perfection. The problem is to discover a method by which the organic content of these soils can be increased which will, at the same time, prove profitable to the cultivator. It is suggested that the solution will be found in the extended growth of fodder crops like *shaftal*, lucerne, berseem, *senji* and *guár*.

No great extension of these fodder crops is likely unless they can be dried and baled for use as fodder for transport purposes. Besides enriching the land, their extended cultivation will help in the feeding of the work cattle and allow of an improvement of the fodder without the use of grain. The albuminoid ratio of dried lucerne and dried *shaftal* is very high, from 1 : 3 to 1 : 4. Actual feeding trials in the Army at Quetta prove that working animals like horses and mules thrive on comparatively small quantities of such fodder.

With proper precautions, drying and baling fodder like lucerne and *shaftal* present no great difficulties even in the arid climate of Baluchistan. First class produce has been prepared, the use of which is likely to reduce the weight of fodder taken by an Army on active service by 25 to 30 per cent, an obvious military advantage. The trials of baled *shaftal* in 1915 and 1916 in the Army at Quetta have proved so successful that it has been decided to purchase 6,000 mds. in 1917 for full tests by the various units of the Fourth Division. Arrangements have been made to grow and bale this amount near Quetta.

III. The Saving of Irrigation Water.

In order to increase the organic matter in the soil by means of leguminous crops it is evident that a good deal of water will be required. This can be obtained by the application of water-saving methods in the growth of wheat, the most important cereal crop of North-West India.

Since the year 1912, a considerable amount of attention has been paid at Quetta to the discovery, under Indian conditions, of the maximum duty of water when applied to wheat. The details of the work are to be found in Bulletins 4 and 7 of the Fruit Experiment Station,

Quetta. The water now wasted by the zamindars on every 200 acres of irrigated wheat is sufficient to produce grain and straw worth a lakh of rupees. Demonstration work on cultivators' fields has been even more successful than the results obtained at the Experiment Station, and this year the wheat area grown with one irrigation is considerable.

IV. SUMMARY.

The object of this paper is to draw attention to the problems underlying the development of agriculture in North-West India. It is suggested that the question must be regarded simultaneously from two points of view—the enrichment of the soil by the extended growth of nitrogen collecting leguminous plants and the saving of irrigation water.

No great extension of the leguminous fodder crops of this tract is possible unless they can be dried and baled and unless the product can be sold to advantage. To introduce this fodder to the notice of all concerned there must be a steady demand and for this purpose the Army is the most obvious purchaser. On this account the trials of baled *shaftal* by the Quetta garrison were initiated and developed. The tests already made show that by the use of such fodders the weight of forage taken by an Army on active service can be reduced by 25 to 30 per cent, an obvious military advantage. The extended growth of these fodders will enrich the land and will increase the production of crops like wheat. A great opportunity for developing the North-West now presents itself in which the Army authorities and the Government can work together to the mutual advantage of both. In such a matter, the Army will not function as a mere spending Department but as a powerful agent of development in that region of India in which it is mainly concentrated.

Once the Army comes into the market for these dried fodders, their extended use is certain. Anyone who has seen the poor feeding of the thousands of cattle engaged in moving produce over the main trunk roads in the North-West, will at once realize how much these fodders would improve the efficiency and reduce the numbers necessary for the work. In urban areas, both cattle and horses are underfed and overworked. The numerous dairies springing up in the large towns are producing milk inferior both in quantity and quality to that which would be possible if the albuminoid ratio of the fodder could be improved. For famine reserves, these baled fodders would be of the greatest use. Such produce is easily stored for long periods, is readily transported and the quantity is easily checked by merely counting the bales. It is highly nutritious and therefore would be a useful reinforcement to such materials as *bhusa* and dried grass whose function would be the dilution of the leguminous hay.

The water necessary for the extended growth of leguminous fodder crops can be found by the adopting of water-saving methods, such as described in the bulletins of the Fruit Experiment Station at Quetta. In Baluchistan, the water wasted every year on every 200 acres of irrigated wheat would grow grain and *bhusa* worth a lakh of rupees. These methods can be applied to the Punjab, Sind and to the Western Districts of the United Provinces. Their adoption would release a large volume of irrigation water which is not only wasted but which is doing a great amount of harm to the country.

Once these improved methods become general in North-West India, the producing power of the soil is certain to increase. The work-cattle will be better fed and the door will be opened for a more intensive cultivation of the land and for the use of heavier and better implements. The country will, at the same time, support a larger population and with the increased production of the soil the prosperity of the people will rapidly improve. Indian agriculture is at present labouring in a vicious circle. The land does not produce enough to admit of the work-cattle being properly fed. Without more efficient oxen it is difficult to adopt the simplest cultural improvements. Only the surface of the soil is scratched

and only the merest skin of the deep alluvial soils of the plains is made use of by crops. This vicious circle, however, can be broken. Nature in the form of the nitrogen-fixing leguminous fodder crops provides the means. The resources of the State, properly directed, are amply sufficient to utilize this means.

The Results of some Experiments on Ragi (*Eleusine coracana*). —*By* L. COLEMAN *and* K. B. VENKATA ROW.

This paper deals with the results of cultivation experiments extending over some eight or nine years and plant breeding experiments extending over four years.

Science of Forestry.—*By* C. E. C. FISCHER.[1]

1. Backwardness of forestry in Great Britain owing to her geographical position and climatic conditions.
2. Progress of forestry in Europe.
3. Advocacy of forestry in Great Britain.
4. Position of forestry in India.
5. Indirect benefits of forests.
6. Necessity for further research in India.
7. Natural phenomena on which the science of forestry is based.

[1] A Study of the Arrowing (flowering) in the Sugarcane with special reference to Selfing and Crossing Operations.—*By* T. S. VENKATARAMAN.

In the work of breeding new sugarcane varieties by raising seedlings, a study of the conditions which lead to the flowering in the sugarcane is naturally one of great importance. Geographical situation, amount of rain received during the period of active growth in the cane, interference with the vegetative growth as resulting from the roots getting pot-bound, and the time of planting combined with the nature of the soil on which the canes are planted, are all found to be factors of some importance in inducing flowering in the cane. It has also been found that, whereas certain classes of canes flower freely year after year, others do not flower at all, or do so but scantily.

Sugarcane varieties show a marked sequence in the time of arrowing and the thick canes, on the whole, arrow earlier than the thin ones. There has been, in the past, a persistent attempt at making the above two classes of canes arrow simultaneously with a view to crossing, as it is believed that in such a cross lie the greatest chances of success at the production of a better class of cane for North India. A certain amount of approximation between the two arrowings has been secured by a careful manipulation of the dates of planting and soil conditions.

A study of the arrows (flowers) of different varieties has shown some interesting differences as regards male fertility between (1) different varieties, (2) Plant *versus* Ratoon crops, (3) different parts of the same arrow, and (4) 'Early' *versus* 'Late' canes. The above study has enabled the separation of a certain group of canes with comparatively poor male fertility to be used as 'Mothers' in crossing operations, and also a selection among the arrows of the same variety as to which to cross and which to self.

A study of female fertility in the cane arrow undertaken with some success for the first time during the arrowing season 1916, promises

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[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

equally important results, the presence of starch grains inside the cells of the style branches appearing to be an indication of female fertility. It is hoped that the above studies will introduce a certain amount of certainty in future selfing and crossing operations.

Bagging is found to have an inhibitory effect on the seed setting in an arrow, chiefly in the case of the thick canes, and a study of temperature conditions inside and outside the bags shows a higher temperature under the former conditions, occasionally by as much as 10 degrees at midday.

Because of the poor and comparatively slow results obtained in other countries by actual emasculation and cross pollination, this method was found to be unsuited for purposes of the station, which was sanctioned only for 5 years, and new methods had to be evolved.

[1] Study of the Sucrose Variations in successive Cane Joints as they attain maturity, with special reference to the Death of the Leaves.—*By* T. S. VENKATRAMAN *and* K. KRISHNAMURTHY RAO.

The main work at the Sugarcane Breeding Station, Coimbatore, is to raise a large number of sugarcane seedlings year after year, grow them to maturity and select the best of these, as regards their botanical, agricultural and chemical characters, for propagation.

The sucrose value of any seedling is ordinarily ascertainable only when the seedling is ripe and is harvested. As this takes sometimes as long as 20 months from the date of germination, an attempt was made to get some earlier indication of it. Besides this, it would save heavy botanical and chemical work on undesirable seedlings to be able to detect the good ones before maturity.

(1) An analysis of that part of an obviously immature cane which bears only dead leaves (analysis up to dead leaf) showed that this part of the cane is, in a certain sense, mature; but the interference of various other factors (such as shooting, lodging, weather conditions) prevented this form of analysis from being fully useful.

By comparing the analyses, however, of the *same, cane*, up to the highest dead leaf (Dead leaf analysis) and up to the point where the ryot ordinarily cuts the cane for the mill (Ryots' sample analysis), it was found that, whereas the two figures show very great differences when the canes are immature, they practically coincide at the time of maturity. Here then we have a new method of ascertaining the maturity of a cane.

(2) By cutting the canes into successive pieces from the base upwards, and analysing these separately, a better result was obtained.

(*a*) In a very immature cane the highest sucrose content was found in the lowest section.

(*b*) As the cane ripens this region of highest sucrose content gradually moves upwards.

(*c*) If different canes of the same variety are sectionally analysed on different dates, the highest sucrose contents obtained on those dates are practically identical.

(*d*) A cane left growing in the ground after it has attained maturity showed rapid deterioration in the basal joints.

The highest sucrose reading obtained by sectional analyses we have called the 'Sucrose Index' of the cane, and it is claimed that this is fairly constant, and will enable a comparison to be made between different seedlings even when they are immature.

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[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

[1] The Planting Industries of Southern India.—*By* R. D. Anstead.

The Planting Industries of Southern India comprise a number of different products of which Coffee, Tea and Rubber are the main crops, and the paper sketches the early history of these three industries.

The oldest planting industry in Southern India is Coffee. The early history of this product is shrouded in mystery and veiled in legends. Coffee is indigenous to Ethiopia and was probably introduced from there into Abysynnia about 875 A.D., and from there it reached Arabia, Syria, Persia, Turkey and other countries in Asia.

No food product has ever had to face as much opposition as Coffee; religious superstition, political opposition, medical prejudice, fiscal restrictions, taxes and duties, but surviving all these it has become a world popular beverage and food.

Tradition has it that Coffee was introduced into South India by Baba Budin in 1600 on the hills above Chickmaglur in the Mysore State. It was certainly introduced from Aden to the Malabar Coast in 1700 and in 1800 references are found to it in Indian literature. There are now some 200,000 acres under cultivation on the hills from the northern limits of Mysore, through Coorg, the Nilgiris, Shevaroys, Pulneys, to Cochin and Travancore.

The next biggest planting industry is Tea. The Tea plant is indigenous to Assam and also in China, and its use and cultivation originated in the latter country, the history of its discovery being purely legendary. The cultivation of Tea in India was first recommended in 1834 and the China variety was tried and failed. In 1840 the Assam Tea Co. was started with the Assam indigenous variety and there are now some 64,000 acres under Tea in Southern India chiefly in the hill tracts of the Nilgiris, Wynaad, Malabar, Cochin and Travancore.

The latest planting industry of any considerable size to be established was Hevea Rubber. Wickham in 1876 brought home to Kew the first supply of seed of any size and this he smuggled from the Amazon. Plants raised from this seed were sent to Celyon and in 1879 twenty-eight of these plants were put out at Nilambur. About the same time a number of plants were put out by Ferguson at Poonoor at the foot of the Tammarachery ghaut and 60 of these survive to-day. The trees were neglected and the experiment considered a failure till Proudlock in 1902 reported on the west coast country as being suitable for Rubber cultivation. The first Rubber estate in South India was opened in 1902 at Thattakad on the banks of the Periyar river in Travancore. This was quickly followed by other estates and now there are some 60,000 acres under cultivation, and Rubber which in 1770 was only used to erase pencil marks has become one of the most important and valuable commercial products in the world.

The Planting Industries of Southern India are now so firmly established that it is apt to be forgotten that it is only comparatively recently that they were introduced.

Every year the Planting Districts are developing, the means of transport are improving, the mechanical facilities are extending, and in the rush of development the romance of the early days, the memory of the pioneers and their difficulties, their British pluck and determination, are apt to be crowded out and forgotten.

Agricultural Insurance.—*By* J. S. Chakravarti.

The paper discusses whether Indian agriculture satisfies certain conditions which are necessary for making a scheme of agricultural-insurance

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[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

practicable in India. The following three points are especially dealt with:—

(*a*) Under Indian agricultural conditions will a scheme of rain insurance practically serve all the purposes of agricultural insurance ?

(*b*) Can any periods be marked off in the Indian agricultural year the quantity of rainfall in which by itself will practically determine the success or failure of agriculture for the year ?

(*c*) What percentage of deficiency in the normal rainfall should be regarded as a minimum limit for insurance purposes ?

As regards (*a*) and (*b*) the result arrived at is an affirmative answer. As regards (*c*) it is found that the percentage is different under different conditions but a percentage can be arrived at for every risk-fixing period of the agricultural year in any of the homogeneous agricultural areas.

The detailed investigations of the author on the subject of agricultural insurance in Mysore and the concrete scheme which he has drawn up with reference to that area are also referred to in the paper.

"Some Enzymes of Germinating Red Gram"[1] (*Cajanus Indicus*).—*By* B. Visvanath.

The enzymic activities of an aqueous extract of germinated red gram have been investigated and it has been shown that diastase, maltase, sucrase, oxidase, lipase, urease are present together with a rennet-like enzyme.

The main interest, however, attaches to the fact that, although these seeds contain about 23 per cent of reserve proteins, there is no peptase present either in the normal or freshly germinated seed. This enzyme only appears at a much later stage of germination. There is, however, an enzyme present which hydrolyses peptones.

The proteolytic enzymes act best under slightly alkaline conditions while the rest of the enzymes act best when the conditions are slightly acid.

Water Hyacinth (*Eichornia crassipes*) and its Value as a Fertilizer.[1]—*By* R. S. Finlow.

In recent years the growth of Water Hyacinth has assumed alarming proportions in Bengal, Burma, Indo-China, Australia, Florida, etc. In Burma it has caused such difficulties in the navigation of rivers that special legislation has been resorted to with the object of eradicating it. Different measures are being tried in different countries to remedy the evil. The habit and growth of the plant has been described in this paper. With a view to investigate its agricultural possibilities the author in collaboration with Mr. McLean, Deputy Director of Agriculture, Eastern Bengal, carried out a series of experiments at Dacca in the monsoon of 1916 with jute as a test crop. The results show that up to 94 lb. potash (K_2O) per acre with lime, applied to acid laterite soils in Bengal, produces a remarkable effect on the yield of jute. The same result was produced by equivalent amounts of potash in rotted Hyacinth, Hyacinth ash, carbonate of potash and chloride of potash. In the green state the plant is very bulky. The rotted material is also very bulky, being comparable with Farm-yard manure, except in regard to the potash content

[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

which is several times greater. Transport difficulties will, therefore, prevent its use at any great distance from the place of production. The plant can be dried and burnt but, of course, all the organic matter and the nitrogen are lost in the burning. The ash containing 50% of chloride potash in addition to phosphate and lime can be profitably used as a fertilizer. Messrs. Shaw Wallace & Co., of Calcutta, have offered to buy any quantity of Hyacinth ash at Rs. 4 per unit of potash (K_2O) landed in Calcutta. This is equivalent to from Rs. 84 to Rs. 120 per ton of the ash. Further the author mentions that there are already indications that the cultivator has begun to appreciate the agricultural possibilities of Water Hyacinth.

Conditions influencing the Distribution of Potato Blight in India.[1]—*By* J. F. DASTUR.

The author describes the conditions under which the fungus *Phytophthora infestans* was found to occur, and also how it spread all over potato-growing countries from America where it made its first appearance. This fungus was introduced into India from Europe along with the importation of large quantities of seed tubers from infected countries such as England. The potato blight is not well known on the Indian plains, but it is to be found with certainty in Northern India, and that, too, at high altitudes. From the account of the experiments with potato cultivation at Jorhat, Sabour, etc., it seems that at times this blight has also been found on the plains, but the epidemic has always been sporadic and the origin of the disease has been traced to the sowing of diseased seed tubers got from infected sections of tubers after the end of summer.

This discovery precludes the possibility of the fungus establishing itself in the plains and therefore potatoes of excellent quality, though susceptible to the disease in hills, can be grown on the plains without being blighted, provided potato seeds are obtained in summer when the temperature is high enough to kill this fungus.

The Improvement of Cotton Cultivation in the Central Provinces studied from an economic point of view.[1]—*By* D. CLOUSTON.

Early attempts to improve cotton cultivation in the Central Provinces were based on the supposition that improvement in the staple was the chief desideratum, and that this could best be done by introducing long-stapled American and Egyptian varieties and by extending the cultivation of the fine-stapled indigenous variety known as Bani (*G. Indicum*). As the result of the classification of the indigenous cottons and of the work done on cotton by the Department of Agriculture within the last ten years it has been definitely proved that Roseum, one of the six varieties which constitute the Jari mixture of the Provinces, is much superior to all others, in so far as it gives a higher yield of kapas per acre and a higher ginning percentage. The lint of this variety, *viz.* Roseum, has several good qualities to recommend it. It is clean, its colour is good, and it has "bulk." By growing it the cultivator makes an extra profit of at least Rs. 15 per acre. There is a keen demand for this variety and the Department has, through its Seed Farms and Co-operative Seed Unions, been distributing from 1½ to 2 million pounds of Roseum seed each year for the last three years. The area under this new variety is not less than 700,000 acres. Its introduction has added at least one crore

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[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

and five lakhs of rupees to the wealth of the Provinces this year which will cover the cost of the Department of Agriculture in the Provinces 20 times over, and the cost of all the Agricultural Departments in India including Burma about twice over.

Much time has been given to the improvement of Roseum and other promising varieties by selection; and it has been definitely proved that Buri (*G. hirsutum*) is immune to cotton wilt—a fungoid disease which does much damage to cotton in parts of the cotton tract.

Of the many crosses produced the Sindewahi cross obtained by crossing Bani with a *neglectum* cotton is of considerable promise. It gives 36 % of lint to seed while Bani gives 26 % only. Its lint is nearly as good as that of Bani.

It has been proved that the ginning percentage of different strains vary and that the percentage can therefore be increased by careful selection from pure line sowings. The offspring of a mother plant giving a high percentage of lint has been found when taken collectively to inherit this same character, though the percentage given by different plants of the same strain varies. The variation in the percentage of lint to seed in the case of a cotton depends on the quality of the soil, on the rainfall and on the time of picking. The first and last pickings give the lowest percentage. Light soil and an insufficient rainfall both affect the ginning percentage adversely.

Cotton in the Central Provinces is grown in an area of about 4¾ million acres. The soil of this area is almost all 'black cotton,' a stiff clayey loam which suffers from water-logging during periods of heavy rain. Irrigation of cotton is never practised, and the crop is only grown in Districts where the rainfall does not exceed 45″. Experiments carried out on the thin laterite soils of the rice tract have shown that on such soils cotton can with irrigation be grown very successfully with a rainfall of even 60″. It would appear, therefore, that on well-drained soils the rainfall is not necessarily the limiting factor in cotton cultivation.

The Phosphate Depletion of the Soils of Bihar; its effect on the Quality and Yield of Crops of the contingent risks of Malnutrition and Endemic Disease in Cattle and Man.[1]—*By* W. A. Davis.

Section of Physics and Mathematics.

President—The Rev. D. Mackichan, *D.D., LL.D., Principal and Professor of Physics, Wilson College, Bombay.*

Presidential Address.

In opening the sessions of the Physical and Mathematical Section of this Congress I have elected to address you on the history of the development of the scientific spirit in India rather than to follow the usual course of passing in review before you some of the more recent developments in the department of physical research. With these you are, most of you, already familiar or have the means of making yourselves acquainted. I possess no special title to instruct you concerning them; I am more concerned to keep before you the possibilities that exist in India for the growth of an Indian School of Research as judged by the past history of Indian thought in the department of the studies represented in this Section of the Congress and the present attitude of the mind of India towards them.

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[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

The advancement of Science in any country depends not simply on the gifts of individual genius but on the surrounding environment, and both these factors are in their turn largely affected by a nation's traditions and history. This environment has received the form which it presents to-day to a large extent through the influence of Western education which has re-awakened the scientific activities of India, which had long lain dormant, into something of their ancient liveliness and vigour. This Congress is itself a witness to this re-awakening and the Institute of Science which has drawn us to this centre is a concrete exhibition of the resolve of India to enter upon its rightful inheritance. The number of Indian workers in the field of Science who are participating in this Congress proclaims the fact of a Science Renaissance in India.

My own memory goes back to the time of its first real beginnings. When I first came to India, the higher education of this country was largely confined to literary channels, and Science, apart from its relation to certain professional courses of study, had a very insignificant place in the system of higher general education. Pure Science as recognized in our Indian Universities was, to a large extent, a merely theoretical study, acquainting men, no doubt, with the results achieved by experimental research in other lands, but having no definite purpose of training the youth of India in the processes by which these results were reached or of inviting them to enter by similar methods into the same quest. But the generation that has just ended has witnessed enormous changes. Just as in England the period preceding that generation had seen a general revival of the modern scientific spirit and a large infusion of it into the higher education of the country, India receiving something of the same afflatus began later to enter on the same path. Some of the best minds in our Universities began to be attracted into special lines of science study and the really great Indian names which have won distinction in these new fields are those of men whose student career began when this new movement established itself. The eminence which they have attained is a sufficient proof of the aptitude of the Indian mind for such studies. In addition to these, whom we may call specialists, the large number of able students, who have chosen this line of study as part of their general education, are gradually building up an environment composed of men possessed of scientific knowledge and trained to appreciate the value of scientific pursuits. From my own experience of Indian students, I have received the impression that speaking generally the students who select such studies as part of their course are the most thoroughly trained and frequently the ablest men of their respective years.

When we reflect that this Science Renaissance in Europe, so far as methods of education are concerned, is not much more than half a century old, we have reason to be filled with hope in view of the marked advance in this direction which has been witnessed in India in the course of the last thirty years. What is true in regard to England in the matter of University studies is true also of other foreign Universities. The "Physikalisches Institut" of Germany is a comparatively modern development. I remember visiting the Laboratory of the great Helmholtz in Berlin University in the early seventies and finding there only a very modest collection of apparatus not larger than can be seen to-day in any well-equipped College in India. As in England, so there also there were great individual workers; but the education of the community had not yet been penetrated by the new spirit. Lord Kelvin was then at the zenith of his fame; but he, too, was content with a limited laboratory (containing, however, some splendid instruments of precision, the products of his own genius) in no way adapted for the accommodation of a large body of students, able to receive only about half-a-dozen men who conducted researches under his inspiring leadership. Of science-teaching in the proper sense as a University discipline there was little thought in these days. All this has been changed and now here in India almost every stage of education is made to include some kind of training in

experimental work. To-day throughout the Bombay Presidency so great is the emphasis that is being laid on this side of education, so revolutionary has been the change that many institutions are still only struggling towards a compliance with the new demand.

In order to grasp the full significance of these movements let us glance back at the past of India and note the lines along which the mind of India found its development. Let us bring a truly scientific spirit to this inquiry, a spirit which demands the acceptance of well-established facts and not a blind enthusiasm for antiquity. We are not unaware of the existence of persons who sincerely believe and solemnly affirm that there is no modern scientific truth that was not familiar to the writers of the most ancient Hindu Scriptures, who find in the Vedas the steam-engine, the locomotive, knowledge of electricity and even the aeroplane. We may well marvel at the lack of imagination and the ignorance of the most elementary canons of literary criticism that renders such credulity possible. There are those again, persons of an entirely different grade of intelligence who claim for the ancient scientific writers of their country the credit of having anticipated by several centuries the greatest discoveries of more modern times. There is really no need for such an excess of national piety towards a people whose intellectual history is surely rich enough to enable it to dispense with any false accretions.

In studying the progress of scientific knowledge in this ancient land one is struck by the fact that the only sciences within the proper domain of Physics that bulk largely in this ancient history are those of Astronomy and Mathematics, its indispensable handmaid. In this respect India's case is not essentially different from that of all the old nations at a corresponding period in their development.

In India the impulse to the cultivation of the Science of Astronomy came from three sources:—(1) the impression which is made upon the human imagination by the splendid majesty of the heavens and the desire that is thus awakened to understand something of the laws which govern their silent movements, (2) the necessity of a calender of times and seasons to regulate the performance of religious observances, (3) the function which astronomy performs as a basis for systematic astrology. The extent to which these scientific inquiries were fostered by religion has probably been greater in India than in any other country. In India the influence of religion has made itself felt in every department of man's life and even the scientific writer of ancient India regarded their theories and their rules as divinely revealed. In the opening verses of the Surya Siddhánta the Sun propitiated as a deity is represented as saying: "I am gratifiied by thine austerities. I will give thee the science on which time is founded, the grand system of the planets." Mathematical treatises like the Siddhánta Shiromani, the Lilávati of Bháskaráchárya begin, as indeed do all Sanskrit writings, with an invocation to the gods. One cannot but respect the religious feeling which prompts such invocations; but at the same time one cannot forget that the idea that Scripture contains a revelation of scientific truth has proved both in the East and in the West a hindrance to the progress of science.

I. The earliest period of Indian thought, of which we have written records, is represented by the Veda Sanhitas and the Bráhmanas attached to them, a period that we may safely regard as free from Greek and other foreign influence. A great portion of this literature is concerned with the mythological interpretation of nature and its phenómena, a feature which is not entirely absent even from some of the systematic treatises on astronomy of a later age. But there is also a non-mythological element in this old-world view of things. It calls attention to the presence of law and regularity in recurring phenomena of nature, the path of the dawn, the motions of the sun and the moon. We find the beginnings of reflection on these phenomena in the naive wonder so often expressed that the sun though unsupported does not fall down from the heavens. Only two heavenly bodies are mentioned, but it is scarcely probable that the

brighter planets, Venus and Jupiter, could have escaped notice. But that the knowledge of this early period extended to the five planets, there is no evidence. To this age, the year was one of 360 days, *i.e.* 12 months each containing 30 days. Such a reckoning of time, if uncorrected, would inevitably have wrought confusion among the seasons. That this was corrected by some kind of intercalation seems to be suggested by a passage in the Rig-Veda which runs thus: "Varuna knows the month that is born in addition to the twelve." The movement of the sun towards the North is said to last 180 days, and the movement to the South an equal number of days. To bring this into harmony with actual experience, the Sáma Veda states that from time to time the *Ayana* or movement to the North lasts 189 days. This is not science; it is a crude conjecture intended to adjust the solar and lunar reckonings to each other.

To this age belongs also the conception of a zodiac consisting of 27, sometimes 28, constellations known as *nakshatras*. A feature of special interest in this connection is the point from which these *nakshatras* are reckoned. This enables a conclusion to be drawn as to the period to which the list belongs. The most reliable conclusion is that which fixes it in the 12th century B.C.

II. It was only at a much later stage that anything like an astronomical system was formulated, *viz.* in the Sutra period of Brahmanic literature, the age of the Maha'bharat, the Purának and the Buddhistic writings. This period was also free from external influences and the system which belongs to it was purely Indian and national. The Surya Prajnápti (a Jain work) and the Jyotisha Vedánga are typical treatises of this age. The latter is an astronomical hand-book in metre and so concisely expressed that much of it is obscure and difficult of interpretation. According to this system the earth's surface is a huge circular plane in the centre of which stands a mountain of enormous height named Meru on which the gods dwell. This disc consists of successive rings of dry land separated from each other by seas which are also circular in form, the ocean, the seas known as the salt water ocean, the ocean of sugarcane juice, ghi, etc. The inner *dvipa* or continent adjoining Mount Meru has Bháratvarsha as its southern portion. The heavenly bodies circle as gods in their chariots around the mountain in a plane parallel to the disc of the earth. Sunrise and sunset take place when the sun passes out of and enters the shadow cast by the great central mountain. The Jains assume that the heavenly bodies accomplish only one half of their circuit in 24 hours, and are under the necessity of assuming the existence of two suns and of similarly duplicating all the heavenly bodies. It is unnecessary to detail all the shifts to which these early astronomers had recourse in order to explain other important features in the movements of the heavenly bodies. These are all justly ridiculed in the Surya Siddhánta which marks the real beginning of a scientific attempt to explain the phenomena of the heavens.

The complicated and clumsy system which I have briefly sketched with all its elaborate calculations held the field for centuries. Its year of 366 days was inaccurate enough; but that the five years' cycle should have continued in its crude and uncorrected form for centuries and that this system should have been followed over wide areas of the country is sufficient to show that the scientific spirit, which demands a higher standard of accuracy both of observation and calculation, was not yet awake in India. A new stimulus was needed to promote this awakening.

III. That stimulus came, as we shall see from India's contact with Greece. The really scientific period began probably about the fifth century, of our era, at least not earlier than the third century. It extended over several centuries down to the twelfth in which it received its fullest exposition in the writings of the greatest of India's mathematicians. The Surya Siddhánta which was probably the culmination of previous effort to systematize Indian astronomy belongs to some period between

the above limits, and contains the system which has been followed ever since down to the present day.

The system preserves some characteristic Indian features. The period of the revolutions of the heavenly bodies is not defined by numbers of days but is fixed with reference to the Maháyuga or cycle of 4,320,000 years. The number of revolutions completed in this period fixes the duration of each revolution. The sun, the moon, Mars, Jupiter and Saturn are dealt with in this fashion. For Mercury and Venus the procedure and its explanation are different. Their mean positions (this in agreement with the system of the Greeks) are given as the mean positions of the sun; their actual positions, now to the East and now to the West of the sun are explained as due to the action of unseen beings designated "forms of time" which pass through the zodiac and continually draw the planets to them by cords of air. These disturbing beings make the same number of circuits in a *yuga* as Mercury and Venus.

In this system the use of the *maháyuga* and the still greater *kalpa*, which are out of all proportion to the periods required in astronomical observation, shows the strong influence of religion on the scientific methods of India. So dominant was this influence that one of the Siddhántas was excluded from the Smriti simply because it made no use of these periods which enjoyed a religious sanction. This method of periods was essentially unscientific. Instead of measuring the periods as multiples of the year, the year became a submultiple of a particular period and the accuracy of the determination of these smaller periods was sacrificed in the interests of the *maháyuga* into which a definite number of them must be fitted.

The mythological device employed to explain the libration of the nodes of the moon and the apparent inequality in the motions of certain planets is another illustration of the same characteristic.

The question as to the dependence of this system on the teachings of the Greek astronomers is one of long standing. It is natural that India should desire to establish its independence of foreign influence in the development of its astronomical system. The weight of evidence seems to be, however, in favour of the conclusion that the essential features of the new system owe their origin to that contact with Greece which established itself in commerce in the early centuries of our era. The new and scientifically constructed system which is found in the Surya Siddhánta and which has remained practically unmodified ever since, is so identical with that of Ptolemy's Syntaxis that it is difficult to imagine that the two systems had an independent origin. Setting aside peculiarities in the mode of explaining certain phenomena, features that are characteristically Indian, there remains an identity of astronomical method so complete that anyone following the rules of the Indian Siddhánta is bound to arrive at practically the same results as he would have reached by employing the formulae of the Ptolemaic astronomy. It is no argument against the identity of the origin of the two systems to point to differences in some of the determinations given in each. This discrepancy in some minor details is easily intelligible and cannot set aside a conclusion based on complete and minute agreement in regard to fundamental conceptions. It is true that Aryabhatta, whose date cannot be fixed earlier than the third century nor later than the fifth, asserts the doctrine of the rotation of the earth on its own axis as a sufficient explanation of the apparent movements of the heavenly bodies. One can imagine such a single conception arising independently in different minds and it is found also among the predecessors of Ptolemy among the Greeks; but in Greece as in India this fruitful conception fell on unreceptive soil. It was first controverted and then ignored. Only after the lapse of centuries did it succeed in gaining, in the face of enormous opposition, the place which it now permanently holds. It is not, however, possible to accept such mutual independence in the case of two complete elaborate systems both resting on the peculiar theory of epicyclic

movement, both containing similar technical terms and astronomical names. The Greek "kentron" is undoubtedly the origin of the Indian *kendra* and the greek zodiacal names were known to the Indian writers, also the Greek names of the planets.

As to the question of priority as between the two systems, there is every reason to consider that the Greek system was prior to the Indian in time. This however is a less convinciing argument because of the uncertainty which always attaches to such early chronology than the fact that the Greek system was the result of a development which can be traced in successive stages of thought during preceding eras, whereas the Indian system stand out in complete isolation from all that preceded it. There is an absolute gulf between the Siddhánta system in its earliest form and the Puranic doctrine already alluded to, which cannot be bridged. A new influence must be assumed to account for a change so abrupt, for which there was no preparation in the eras which went before.

To my mind this is a consideration which ought to outweigh every other form of argument in leading us to conclude that the Indian system was an offshoot from that of the Greeks.

The system thus formulated has undergone practically no development since the time of its adoption.

But if India has to renounce her claim to be the discoverer of this system, she deserves a renown of really higher value because of the brilliant names which adorn this period. The names of Aryabhatta, Varáha, Mihira, Brahmagupta and Bháskaracharya, to mention only the best known, add a great lustre to this age of Indian research. Greece had developed a mathematical system of wonderful perfection in the domain of geometry. On this was built up her astronomical theory. In India mathematics played a different part. It did not serve as the foundation of the theory but as the instrument of calculation in the practical application of the system, in the solution of problems which were likely to arise. Hence its methods are analytical, embracing a scheme of algebra and trigonometry which marks a great advance in mathematical attainment. Here India can make good her claim to originality. In respect of both arithmetic and algebra India has been the world's teacher. Algebra, although it bears an Arab name, was borrowed from the Indians by the Arabians and our numeral system is not Arabic but Indian.

The representation of the value of numbers according to their position in a decimal scale, the solution of quadratic and bi-quadratic equations and more particularly the solution of indeterminate equations of the first and the second degree, these are a few of the characteristic contributions of India to algebraic progress. The *kuttaka* method for dealing with these indeterminate equations has been described by a great mathematical historian as "the finest mathematical achievement before the time of LaGrange" who, centuries later, re-discovered the method which had long been familiar to the Hindu mathematicians.

India has the credit of having based its trigonometry on the *Sine* instead of the *Chord*, a change which has greatly contributed to the progress of this branch of mathematics.

Aryabhatta used 3·1416 as the value of π, a very accurate expression, nevertheless some of his successors with a characteristically Indian love for forms of a symmetrical or symbolical character frequently employed $\sqrt{10}$ as the value of this ratio, a much less accurate expression than $\frac{22}{7}$ or 3,1416, values employed by earlier writers. These Hindu mathematicians came very near to the infinitesimal calculus; yet one of the greatest of them stumbled into error in calculating the volume of the pyramid and the sphere.

One may feel disposed here to ask these two questions:—Why did geometry prove so attractive to the Greek mathematician and algebra to the Indian? and Why did Greece pursue its mathematics to such a wonderful degree of completeness, while India even when on the threshold of great developments stopped short and never advanced any further on

purely Indian lines? I believe that the answer to these two questions is to be found in the speculative character of the Greek mind on the one hand and the eminently practical character of the Indian mind on the other. To the Greek, mathematics was a field of mental exercise cultivated mainly in order to satisfy the craving for the ideal that was a characteristic feature of the Greek mind. Geometry was not pursued in the first instance for any definite practical purpose, chiefly as a study of ideal relations, a department of ideal truth. On the other hand the Indian cultivation of algebra was stimulated by the necessities of his practical life. Astronomy was essential for the exact performance of his religious duties and for astronomical calculations algebra and trigonometry were the necessary instruments. These instruments he furnished and kept in readiness for the operations that were necessary, and this to a degree of perfection elsewhere unknown at that ancient time; but beyond this the science had little further interest for him and its development stopped short when the necessary purpose had been accomplished. What led the Indian mathematician to busy himself with the solution of the indeterminate equation? The answer is that there was an astronomical, and ultimately astrological, necessity for it in connection with certain inverse problems that arose out of the calendar.

Now many have been in the habit of regarding the Indian as so intensely speculative as to be in danger of missing the practical in life and action. It would rather seem to be true that the bent of the Indian mind is towards the practical and not towards the merely speculative. I have sometimes wondered whether we may not discern even in the strictly philosophic efforts of the thought of India something of the same practical purpose which runs through its mathematical achievements. Indian philosophy was no mere speculative exercise, it was not pursued simply to satisfy an intellectual craving; it was something pursued with a view to the practical ends of the religious life. No doubt it demanded an intellectual effort of a high order and employed in its service intellects as great as any which have grappled with the great problems of existence; but emancipation from a condition from which the soul strove to free itself was the goal of all this high speculative endeavour. Perhaps we may discern in this also the reason why India's speculative efforts in philosophy, like her achievements in mathematics, came to a standstill and succeeding generations were content simply to attach themselves to one or other of the leading schools, once they were satisfied that they had found in it the practical satisfaction that their religious instincts seemed to demand. I merely suggest this as a possible explanation of facts peculiar to the history of the development of Indian thought and in opposition to the generally accepted view that the Indian mind is so wedded to the speculative that it is less fitted to devote itself to the tasks of severe science.

From the rapid survey I have attempted it appears then that India like the rest of the world was in the ancient time still far from the paths of the modern scientific method. Even its later efforts were confined to the reduction into an ordered system of the manifold phenomena which pressed themselves on their attention; the external framework, not the inner connections of the phenomena, was that which occupied their thinking. The dynamical foundations of their favourite science remained beyond their ken and were not reached by them or any other peoples until the modern age represented by a Kepler and a Newton. I have seen it stated that Bháskaracharya had foreglimpses of the law of universal gravitation; but this statement rests on a misapprehension of the real significance of that law. Let me simply quote the statements on which this claim on his behalf has been made.

They are mainly these: "The earth stands firm by its own power without support in space. As heat is in the sun, coldness in the moon, ... so immobility is in the earth by nature."

"The earth possessing an attractive force draws towards itself any

heavy substance situated in the surrounding atmosphere, and that substance appears as if it fell. But whither can the earth fall in ethereal space which is equal and alike on every side ? "

It may be admitted that the idea of attraction is a step in advance of those who see bodies fall without attempting to inquire why they fall, but we are still far from anything like an anticipation of the great generalization of Newton, a generalization which was based on a theory of attraction which had been verified by elaborate calculation and which gave the key to the explanation of all the heavenly movements. Let every credit be given to Aryabhatta and to Bháskaracharya, great mathematicians both; but let us not transplant them into a world of ideas that had not yet dawned on the thought of the men of any land. I have been endeavouring to show that Indian science in all its ancient stages was dominated by a specific practical religious purpose and was hampered in its freedom by certain traditional conceptions which had acquired a religious sanction. The stage of the free independent study of nature had not yet been reached. Nor was there a scientific effort after ideal exactness. One of India's great astronomers, Bháskaráchárya, defends his predecessor Brahmagupta from the charge of having refused to admit a periodic motion of the equinoxes. He says that the inconsiderable quantity of the procession which was not marked in his time was the reason why he omitted it from his system ; but that, now that it had become sensible in amount, it is taken into account. This plea for inaccuracy is most remarkable. It confirms the view I have stated, that to the mind of India what was sufficient for practical purposes was sufficient also for scientific statement. This is one of the inherited tendencies which we sometimes meet with in the students of to-day. Ideal exactitude has not the place it ought to have in our investigations. We are too much disposed to be satisfied with what will sufficiently serve a particular purpose.

What we should aim at in view of the widening field of Indian scientific inquiry is that sense of absolute freedom which is the vital air of the physical investigator and that exactness of observation and inference which is its necessary complement. It is a hopeful sign of progress that our Indian students of science are beginning to enter into and enjoy this atmosphere and that new ideas of accuracy are being eagerly assimilated.

Nor is there any room for national presuppositions or predilections in this field of study. It is a field in which national distinctions are absolutely unknown. There is no commonwealth so comprehensive as that of science, none in which the brotherhood of men and their share in a common inheritance is so completely realized. The facts with which we deal are the common possession of us all, and the laws which we seek to unfold stand to all of us in exactly the same relation, and success in their unfolding ministers to all of us the same mental satisfaction, the same intellectual joy.

On the beneficent influence which the development of scientific research is bound to exercise on the education and the life of the people of India it is not necessary now to dwell. Suffice it simply to say that amongst these benefits must be included a new reverence for truth and for Him whose thoughts are being continually revealed to us in their overwhelming majesty and power. This new movement of thought laying hold of the practical tendencies of the Indian mind is destined to call forth its ingenuity and resource in dealing with the many practical problems which will continually emerge as India moves forward to higher developments. And as in its past history the mind of India received a decisive impulse from its contact with the science of Greece through the accident of commercial relationship, may we not expect a new intellectual movement still more conspicuous and more fruitful from India's closer contact, in its intellectual life and in its imperial destinies, with that other nation of the West with which in the providence of God it is now linked in an indissoluble union.

On the Theory of the Periodic and Cyclical Vibrations of Bowed Strings.—*By* C. V. Raman.

The author has found that, in a considerable variety of cases, the motion of a bowed string instead of being periodic, becomes cyclical in character. Some photographic records illustrating this fact will be shown as lantern-slides, and the theory of these cases will be discussed in the light of the corresponding theory for the periodic forms of vibration.

On Discontinuous Wave-Motion.—*By* C. V. Raman *and* Ashutosh Dey.

Continuing the investigations described in the Phil. Mag. for Jan. '16 jointly by C. V. Raman and S. Appaswami Aiyar, it has been found possible by the authors to obtain, experimentally, wave forms containing two equal or unequal discontinuities, of the same sign or opposite signs, in each period. The resulting vibration forms are found to be of considerable interest in acoustics.

The Cause of the Abnormal Displacements in the Sun's Spectrum.—*By* T. Royds.

Difference of vapour density in the sun and arc has been suggested to account for the abnormal displacement of certain lines in the sun's spectrum, and though no objections have been raised against this hypothesis, attempts at direct experimental proof have failed.

Types of Electric Discharge.—*By* D. N. Mallik *and* A. B. Das.

In this paper, the authors use vacuum tubes of ordinary pattern (electrodes consisting of thin rods of aluminum) and show, that the discharge passes through the various stages previously obtained with a De La Rive tube, 'showery,' 'band,' and 'glow,' so far confirming the theory worked out in their former papers on the subject. In accordance with that theory it is during the second stage that the discharge should behave like a flexible wire carrying current. This is verified by experiment. When the discharge is striatory, the effect of the magnetic field due to a rectangular coil of wire with two of its sides parallel to the electrodes and carrying current has been studied. This is likely to lead to a theory of striatory discharge, on which the authors are now engaged. The effect of the length of a discharge tube on the change in the types of discharge is most marked. But anything like a complete explanation of it is impracticable at present.

The Cathode fall from different metallic Cathodes.—*By* H. E. Watson *and* C. R. Paranjape.

This work, a preliminary account of which was given at the last Science Congress, has been continued. A large number of detailed observations have been made with regard to the conditions under which the cathode fall is the same as the total potential across the tube.

The cathode fall has been measured in different gases for about 25 metals, and it has been found that for most of these it is almost constant within the limit of experimental error. A few metals, however, are abnormal, and these are separately discussed.

Interference Fringes formed by a grating.—*By* C. K. VENKATA ROW.

A system of interference bands was observed extending throughout the spectrum when using a celluloid copy of a Rowland grating mounted on glass as a reflexion grating, the light being incident on the grating face first. The theory of these bands is worked out and experiments given in confirmation thereof.

On the Interference Pattern of thin films at nearly critical incidence.—*By* E. P. METCALFE *and* B. VENKATESACHAR.

A somewhat convergent beam of monochromatic light is made to fall on to a plane parallel air film enclosed between two glass plates immersed in water at and near to the critical angle of incidence. The interference pattern so formed is viewed in a telescope focussed for parallel light and is found to consist of nearly straight parallel fringes of varying thinness. This is shown to be due to the rapid variation in the reflecting power of the air-glass surface in the neighbourhood of the critical incidence. The fringes have been photographed with light polarised in the two principal directions. The theoretical intensity curves have been drawn and have been found to agree with the photographs. A new set of interference fringes is observed when the reflecting system is placed between crossed Nicol prisms. These fringes have also been photographed and are accounted for theoretically.

A Note on the Efficiency of the Aeroplane Propellers: Meaning, Measures and Tests, with an Outline of a new Method of Procedure.—*By* S. S. NEHRU.

The following is a section-wise abstract of the above paper which is a corollary to a technical paper, that has been submitted for publication in Europe.

Section 1. Introductory and explanatory. The disturbed motion in the medium set up by the propeller is only a specific case of the turbulent motion of fluids, which is the province of the physicist, and not of the technician. In considering and measuring turbulence, the root-problem of aerodynamics, an abrupt departure is made from the classical methods of the air-laboratory, and the study of the efficiency of the propeller is placed on a scientific basis.

Section 2. The propeller, function, redefinition, best types. The propeller is re-defined as a transformer, converting rotative into propulsive horse-power. Leading types are considered from the standpoint of efficiency:—(*a*) the Ratmanoff, subject of tests in England, (*b*) the Chauvière, the commonest in use, (*c*) the Bigourdan, a "circular wing," the efficiency of which in the laboratory is four times that of (*d*) the Guthemburg, the best German Type.

Section 3. Considerations of efficiency, anomalies. A series of anomalies are presented. Thus, the above types are fundamentally unlike, and they are all supposed to possess the same high order of efficiency; classical methods, as shown by the technical reports of the British Advisory Committee for Aeronautics, suppress turbulence, which is precisely the main characteristic of fluid motion; anomalies in the results reached in those reports are explained; so also the anomaly of a propeller, efficiency 80%, converting 50 HP into only HP 20; etc.

Section 4. Criticism of current conception of efficiency, and methods of procedure. It is shown how the current conception of efficiency is reponsible for the above, and other anomalies; and the imperfections of the classical method which measures the mere mechanical pull, in con-

fined space, of the artificially and arbitrarily mounted propeller, by the pull-balance, are fully set forth.

Section 5. A complete conception of efficiency should allow full weight to all the multiple factors of natural aspiration.

Section 6. Factors affecting efficiency are fixed under the categories of—space-elements, force-elements, time-elements, from the point of view of the space-distribution of thrusts, at any time, in the medium agitated by the propeller.

Section 7. Effect of the preceding factors on efficiency are fully analysed. Leading up to—

Section 8. The fundamental test of efficiency, which covers two points:—(1) Is the thrust-system, in the natural space, maximum? (2) Does it grow in the minimum time?

Section 9. The measure of efficiency. The space-map is defined. The construction of the space-map is explained. The measure is discussed; and the apparatus, which was actually used with good results, communicated. The gauge, which is the novel feature of the apparatus, and which permits of the actual measurement of the turbulent motion, is described. The working of the gauge is shown step-wise.

Lastly the action of the guage is placed on a theoretically rigorous footing, by basing it on the mathematical theory of an oscillating fluid column and the attractive or repulsive force between spheres immersed in it and placed close together, such oscillatory fluid-motion being the type of turbulent-flow in the medium in which the propeller is at work.

To conclude, the method records flow-effects just as they occur, just where they occur.

The Duration of School Life, a New Measure of Instruction and a Test of Educational Administration.—*By* R. LITTLEHAILES.

The method of calculating the duration of school life adopted by the Government of India is criticised and shown to be imperfect. Three other methods of calculating it are proposed and discussed. From the value of the duration of school life thus calculated and from the number of pupils under instruction at any time, a new measure of instruction is proposed. From a comparison of the rate of variation of this new measure of instruction with the rate of variation in the number of pupils under instruction, it is proposed to test the efficiency of the Educational Rules or administration in force at the time of the comparison. The variation in the cost of a uuit of instruction is also referred to. Statistics from the year 1895 up to date, *i.e.* for twenty years, are analysed.

On certain Integral Functions defined by a Taylor's Series with extensions to the case of the $n - pb$ Power Series.—*By* K. B. MADHAVA.

Section of Chemistry.

President—DR. J. L. SIMONSEN, *F.I.C., Professor of Chemistry, Presidency College, Madras.*

Presidential Address.

GENTLEMEN,

I wish in the first place to say how very greatly I appreciate the honour of being asked to preside over your deliberations at this meeting. My two predecessors in this chair set a most excellent precedent in not delivering a Presidential Address, and it is only after much consideration

that I have decided to break away from this precedent. I do so for the following reasons. Science—the Cinderella of Education—appears at last to be coming into her own, and it behoves us as chemists in India to show that we are prepared worthily to uphold the dignity of our Science.

I do not think that we can say that all is well with chemistry in India, rather would I say that very much is bad. It is only a short seven years since I came to India and I feel some diffidence in criticising the present conditions in the presence of such veterans as my friend Dr. Ray, but perhaps being fresher to the country I may more clearly see the needs and failings if I may not quite so well appreciate the difficulties.

When I first came out, the University of Madras was still slumbering under the old régime, although new courses of study had been arranged and were shortly to be introduced. For the old degree all that was required of a chemistry student was that he should be able to analyse a mixture, the use of the balance was apparently considered to be too difficult and yet his theoretical knowledge, according to the syllabus, would not have disgraced an Honours student. Even for the higher degree, the M.A. in chemistry, practical, physical, or organic chemistry were unheard of. Although unfortunately we still suffer from the after-effects all this is altered now and in our Honours courses, I may say, I think without undue exaggeration, that the training given to the student in chemistry does not fall below the standard of that given in the majority of Western Universities. The Pass degree, too, if it is improved in the manner now proposed, will be quite satisfactory. We see then that there has been progress, and rapid progress too; but yet I say that chemistry, not only in this Presidency but in India in general, is not in a satisfactory state. When we consider the number of first and second grade colleges, the number of men engaged in teaching the subject, we cannot but be amazed at the very small amount of original work which is being done. Let it be understood that I am referring solely to educational institutions and not to special research laboratories such as we have at Pusa, Coimbatore and Bangalore.

As Secretary of this Congress since its commencement I have had a unique opportunity of judging of the number of those who are doing research in chemistry in India, and I am astonished at their fewness. Only in Bengal does there appear to be more than one college in the University in which research is done. It might perhaps be desirable for us to examine into the cause of this and see how it can be altered, because I feel that until there is a healthy research atmosphere in all the Universities and University colleges, we shall see no real advance in the position of chemistry in India.

I would submit, for your consideration, what I consider to be the four main causes of this paucity of research: (i) that in many colleges the staff are insufficiently trained. I do not intend to throw any aspersions on a hardworking, worthy body of men; it was not their fault that when at college they received a training which did not fit them for higher teaching or research, and for the reasons which I shall mention in a moment they have had no subsequent opportunity to improve their knowledge; (ii) that the majority of colleges are very much understaffed. This, in my opinion, is the most serious defect and the main cause of the present state of affairs; (iii) the low rate of pay in academic posts; (iv) the present method of promotion by seniority and not by merit.

Of the other causes to which the lack of research has from time to time been ascribed, I may perhaps mention two, namely want of library facilities and want of a scientific atmosphere. I cannot bring myself to believe that these are really serious factors.

It is always a somewhat delicate matter to discuss the question of the pay offered in the various collegiate appointments. It appears to me, however, that unless the scale of pay is improved it will be impossible for us to attract the best intellects. It is not that I consider the rate of pay

at which the lecturers and demonstrators commence, to be inadequate—it compares favourably with that offered in other countries—but rather it is the future prospects which are so poor. In many cases the lecturer can, under no circumstances, hope to get more than Rs. 150 and that only after many years of arduous service. Now I do not think that anybody can consider this to be an inducement for a clever student to enter upon an academic career, and the obvious result will be, therefore, that instead of there being any improvement in the staffs of colleges, they will more and more tend to deteriorate as other openings arise from the increase of the development of the natural resources of the country.

The tendency for the teaching and research to deteriorate is further enhanced by the fact that in practically all cases promotion is made by seniority and not by merit. I am quite willing to admit that in the larger services, such as the various Government educational services, it will be a matter of considerable difficulty to make any change in the system, but I really cannot imagine that it is beyond the wit of man to devise some more satisfactory scheme than the present. One can but too well understand the feelings of a brilliant young investigator, when he sees a colleague promoted to a higher post, who has done nothing to render himself worthy of it beyond putting in a certain number of years of service. This system must be radically altered if we are to see research really develop.

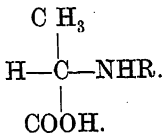
I have thought it of interest to look into the matter of the staffing of the various colleges teaching chemistry up to the degree standard and I find that in many colleges, not only in this Presidency of Madras, but also elsewhere, it is considered sufficient to have one lecturer in chemistry to look after not only large Intermediate classes but also the B.A. (or B.Sc.) classes. He is perhaps assisted by a demonstrator without any previous teaching experience who is very often of little help. Not only is this the case, but in some colleges a lecturer is expected to teach both chemistry and physics. So long as this continues we cannot hope to see any improvement. On a recent occasion I pleaded elsewhere for an increased staff in a college which was to be affiliated in chemistry, and I was told that in view of the fact that other colleges had no larger a staff, the management saw no reason why the staff should be increased. In this case it was not a question of finance, money was available, laboratories were in process of construction, but the authorities, apparently, although they were not men of science, considered that they knew better than their scientific advisers.

Gentlemen, I have dealt with this question of the staffs of colleges at some length because I feel it to be of vital importance. We have to meet in this country the same opposition as has to be met in England. The heads of colleges, the managers of schools, in short the authorities in charge of education have, as a rule, little or no appreciation of the importance of science or of its requirements. It is perhaps too late in the day for us to educate them but we must make sure that the rising generation is not similarly steeped in ignorance. We must insist that our science shall be given a fair chance and that our teachers shall not be sweated—I use this strong word with intent—but that they shall be given opportunity for original work. For I very strongly hold the view that no man can remain a first class teacher or inspire his students who is not actively engaged in research.

Gentlemen, the future is in our hands. Let us prove ourselves worthy.

The Stereochemistry of Alanine Derivatives.—*By* C. S. Gibson *and* J. L. Simonsen.

The authors have for a considerable time been engaged on the stereochemical study of compounds of the type:—



Where R is an acyl group.

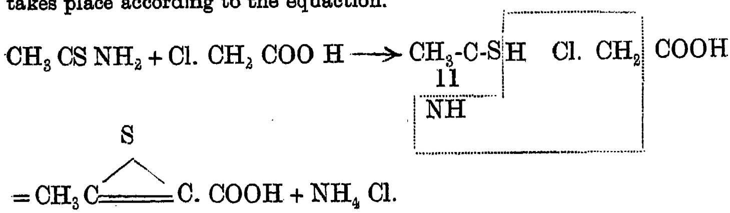
The objects of the research were discussed and a brief account was given of the results so far obtained and the conclusions that may be drawn therefrom.

The Nitration of Isomeric Acetylamino Methoxy Benzoic Acids.—*By* J. L. Simonsen *and* M. Gopala Rau.

The authors have investigated the products formed on the nitration of the four isomeric acids, 3-acetylamino-2-methoxy benzoic acid, 5-acetylamino-2-methoxy benzoic acid, 4-acetylamino-3-methoxy benzoic acid, and 3-acetylamino-4-methoxy benzoic acid. They discussed the bearing of the results obtained on the general problem of substitution in the benzene nucleus.

Synthesis of a Derivative of the lowermost Homologue of Thiophen.—*By* P. C. Ray *and* M. L. Dey.

By the intraction of thioacetamide and monochloracetic acid a crystalline compound is formed which is found to be methyl-carboxyl ethine sulphide (or carboxyl propine sulphide). The reaction evidently takes place according to the equaction.



Formation and Re-action of $\alpha\alpha\beta$ and $\alpha\beta\beta$ Tribromophenyl propionic Acids.—*By* J. J. Sudborough.

The bromination of the α and β bromo and chlorocinnamic acids and their methyl esters has been examined.

The elimination of hydrogen bromide from the bromocinnamic acid dibromides has been studied and the relative yields of cis and trans dibromocinnamic acids determined.

The Oil Contents of some South Indian Oil Seed Cakes.—*By* J. J. Sudborough.

The author has estimated the percentages of oil contained in the following types of cake :—

Copra, gingelly, groundnut, castor, hutchellu, hongey and ippe.

The cakes were from different parts of South India and were prepared either by means of an Anderson Expellor, the ordinary country ghany mill, an iron mill or a hydraulic press.

The results indicate that in most cases with the exception of castor seed cake, an appreciable portion of the oil is left in the cake.

Certain samples of copra cake were found to contain as much as 30% of oil.

Experiments on the Distillation of Sandal Wood Oil.—*By* J. J. Sudborough *and* H. E. Watson.

The Authors describe :—

1. A tilting still for dealing with about 200 pounds of chipped wood.
2. The variation in the physical constants of the oil as the distillation proceeds.
3. The results of re-distilling the oil with superheated steam at different temperatures.
4. The results of vapour pressure determination.

They have compared :—

(*a*) The results obtained with new wood and wood one year old.
(*b*) The yields of oil obtained from spiked and unspiked wood.
(*c*) The yields obtained from (1) healthy, (2) dying, (3) dead wood.

The Distillation of Mysore Forest Woods.—*By* H. E. Watson, J. J. Sudborough, K. Umanatha Rao, *and* K. S. Dheerender Doss.

Some twenty samples of Mysore forest trees supplied by the Forest Department as representing the commoner kinds of wood available in the State have been submitted to distillation in a specially constructed retort, and the products analysed to determine the yields of charcoal, acetic acid, methyl alcohol and tar.

The retort is electrically heated and will be described, and the results so far obtained will be given.

Direct Nitration by means of Nitrous Gases.—*By* R. L. Datta *and* P. S. Varma.

By nitration by means of nitrous gases, ortho-cresol gives 3-nitro-cresol and 3 : 5-dinitro-o-cresol in good yields. m-cresol gives 4-nitro-m cresol and 6-nitro-m-cresol. From p-cresol, 3-nitro-p-cresol is obtained. p-hydroxyphenylarsenic acid yields a mono-nitrocompound. Acetophenone gives m-nitro-benzoic acid, iodo and bromo benzene yield p-nitroderivatives, o-iodo toluene yields a mono-nitro product. Chlorbenzene is not acted upon by nitrous fumes. By the treatment of benzene and toluene in the heat, traces of nitro compounds are formed which have however no practical interest.

Iodination by means of Nitrogen Iodide or by means of Iodine in the presence of Ammonia.—*By* R. L. Datta *and* N. Prosad.

The action of iodine and ammonia has been studied in the following cases. Phenol gives a quantitative yield of 2 : 4 : 6—triiodophenol. Ortho-cresol, para-cresol and meta-cresol give in quantitative yield diiodo-o-cresol, diiodo-p-cresol and triiodo-m-cresol respectively. From thymol, 6-iodo-thymol has been obtained. 1 : 4 : 5-xylenol has been found to yield a mono-iododerivative. Phenolphthalein yields tetraiodophenolphthalein. Ortho-nitrophenol gives on iodination 2 : 4-diodo-6-nitrophenol which yields a stable ammonium salt. Meta-nitrophenol yields 2-iodo-3-nitrophenol which however yields an unstable ammonium salt which decom-

poses on keeping. From paranitrophenol 2 : 6-diiodo-4-nitrophenol has been obtained which does not give any ammonium salt. 3-nitro-1 : 4-cresol has been found to yield 5-iodo-3-nitro-1 : 4-cresol and a stable ammonium. The special feature of this reagent is that in all cases quantitative yields of the products are obtained. In view of the fact that both ammonia and iodine in the mother liquor could be conveniently recovered, these methods would serve as the best modes of preparing these iodophenols and iodonitrophenols on the large scale.

The following iodinations of hydroxyacids have been achieved. Salicylic acid gives 5-iodo-salicylic acid. From m-oxybenzoic acid 6-iodo-3-oxybenzoic acid has been obtained. p-oxybenzoic acid yields 3 : 5-diiodo-6-oxybenzoic acid. A mono-iododerivative is obtained from p-hydroxyphenylarsenic acid.

It has also been found that dimethylpyrone is readily iodinated by means of nitrogen iodide with the formation of 2 : 6-diiodolutidone which form a stable hydrochloride. From pyrrol, a quantitative yield of tetraiodopyrrol has been obtained and the reaction could be used for the quantitative estimation of pyrrol. Acetylene forms with great ease tetraiodoethylene and phenylacetylene yields triodostyrol.

Nitrogen iodide also acts as an oxidising agent. For instance, quantitative yields of benzoic acid and quinhydrone have been obtained from benzaldehyde and hydroquinone respectively. Nitrogen iodide also effects the breaking up of organic compounds with the formation of iodoform as the end product of the reaction. Iodoform has been found to be produced from acetone, methylethylketone, diethylketone, acetylacetone, acetylmethylpropylketone, acetylmethylhexylketone, acetoxime, acetophenoneoxime, malonic ester, acetoacetic ester, diethylamine, triethylamine, ethyl and propyl alcohols, and mesityloxide.

On the Decomposition of Nitrogen Sulphide.—*By* F. L. Usher.

When pure yellow nitrogen sulphide is sublimed in vacuo over silver gauze at 100°, a blue sulphide of nitrogen is formed very slowly, accompanied by the evolution of traces of nitrogen. At 115° the formation of the blue compound proceeds a little faster, and the rate is considerably increased at 125° and 139°. If the yellow sulphide contains free sulphur, a new ruby-red sulphide is formed at 125°, and this has the same empirical composion as the blue sulphide. On heating a mixture of yellow nitrogen sulphide with sulphur in vacuo at 125° without silver gauze, a dark red volatile liquid is produced, which analysis shows to be nitrogen persulphide $(NS_2)^x$. The persulphide is not formed by direct combination of the yellow sulphide with sulphur, but by the decomposition of an unstable intermediate compound, probably N_2S_3. A method is given for analysing very small quantities of the sulphides.

A new method of preparing Colloids.—*By* J. C. Gosh.

If we electrolyse a dilute solution of silver nitrate with a point cathode of platinum by a direct current (2·5 milliamperes) and if during this process of electrolysis, electric oscillations be impressed on this system, the metal ions, as they are liberated, do not adhere to the cathode. The metallic particles run away from one another, and remain suspended in the solution. However the amount of silver held in suspension corresponds to the quantity of direct current passed through the electrolytic cell. The electric oscillations, therefore, only endow the ions as they are liberated, with a force of mutual repulsion.

In this way, the finest solutions of silver, which are green in appearance, can be easily had. Mercury solutions can also be obtained by this method. Futher experiments to determine whether other kations behave in the same way, are in progress.

The wave-length of the electric oscillations used is 73 cms.

On the determination of ozone, oxides of nitrogen and hydrogen peroxide in atmospheric air.—*By* B. Sanjiva Rao.

A summary of previous work is given, and the methods employed are criticised. A method has been devised, in which three samples of air, each of 5—10 litres, are shaken for several hours with an extremely dilute standard solution of sodium nitrite, rendered slightly alkaline. The first sample, prior to treatment with the nitrite solution, is passed through a tube of chromic acid crystals, whereby hydrogen peroxide is removed; the second sample is passed through powdered manganese dioxide, which destroys both ozone and hydrogen peroxide but is without action on oxides of nitrogen; the third sample is collected directly. It is shewn that ozone, even in excessive dilutions, oxidises sodium nitrite in solution rapidly and quantitatively in accordance with the equation. $NaNO_2+O_3=NaNO_3+O_2$. Hydrogen peroxide oxidises the nitrite similarly, but only in acid solution. By estimating the amount of nitrite remaining after shaking with the three samples of air, the amount of ozone, hydrogen peroxide, and oxides of nitrogen can be calculated. The estimation of nitrite was carried out colorimetrically by the method of Griess, and using naphthylamine and sulphanilic acid.

The results of some experiments on the air at Bangalore are recorded.

[1] *Chalybeate Waters from tube wells in the Punjab.* Their significance to the Municipal Engineer and to the Manufacturer. —*By* J. H. Barnes *and* Arjan Singh.

A brief history is first given of chalybeate waters and the difficulties which have been experienced in making use of such waters for municipal purposes and in manufactories.

The problem of iron-depositing waters has arisen in the Punjab where deep waters are being tapped by tube wells and a detailed study of such waters from different parts of the Punjab is described. The presence of iron bacteria well known in Europe but hitherto unrecorded in India—such as *Leptothrix ochracea*, *Gallionella ferruginea* (Ehrenberg), *Spirophyllum ferrugineum* (Ellis) and *Crenothrix|Polyspora* (Cohn) is demonstrated.

The sub-soil waters of the Punjab show a marked increase in the amount of ferrous iron they contain as the distance from the Himalayas —the source of the water—increases, thus proving a steady flow westwards of sub-soil water.

The contact of these ferruginous waters with an aerating agent such as sea water offers a feasible explanation for the formation of the mineral *limestone*.

The paper includes a description of the methods of analysis used and full tables of the composition of tube well water before and after the monsoon. In conclusion, recommendations are made for the purification of these ferruginous waters when making use of these for municipal or manufacturing purposes.

Some biochemical factors in the reclamation of alkali soils.— *By* J. H. Barnes *and* Barkat Ali.

The paper first reviews in brief the sources and nature of the saline matter which causes sterility in alkali soils. The view is advanced that sterility in such soils is not due to any specific toxic effect of the chemicals

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[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

comprising the saline salts but is due to the physical effect they exert on the protoplasm of the plant cell in causing plasmolysis.

Chemical analysis alone is useless in examining a saline soil with a view to determining either the cause of sterility or the degree of cure effected in reclaiming such a soil for agricultural purposes. It is pointed out in the paper that the direct measurement of the osmotic pressure of the soil salts in solution would be too difficult and lengthy to be of practical utility and the indirect measurement by crop tests lengthy and expensive. This working result is achieved by the use of soil bacteria and measuring their rate of chemical activity. The paper describes the biochemical methods used in determining the chemical activity of carbon oxidising organisms, the ammonifying and nitrifying bacteria and the nitrogen-fixing activity of bacteria of the *azotobacter* type.

Tabulated statements are given of the study of the soils of an experimental farm at Narwala in the Punjab where saline land has been sucessfully reclaimed and abnormally high yields of crops obtained; as much as 37½ maunds of wheat per acre being obtained in one field.

The paper contains a tabulated statement of crop outturns on the Narwala farm where the biochemical methods described in the paper have been used in reclaiming the land.

Metallic Derivatives of Alkaloids. Part I.—*By* J. N. Rakshit.

The sodium and potassium derivatives of codeine and sodium derivative of narcotine are obtained by boiling them in benzene; and calcium morphine is prepared by rubbing morphine with lime in rectified spirit.

The Sodium Bisulphite Test for Formic Acid and an attempt to reduce the Aliphatic Acids to their corresponding aldehydes.—*By* S. C. Chatterji.

Contrary to Comanduccis' statement it has been shown that sodium bisulphite is not at all a convenient reagent for the detection of formic acid. The result of an attempt to reduce the aliphatic acids to aldehydes using Zn. and Mg. has then been given.

Detection of Lactic and Glycollic Acids and a Suggestion about the Constitution of Morphine.—*By* S. C. Chatterji.

After dealing with certain colour reactions of lactic and glycollic acids based on their conversion into acetaldehyde and formaldehyde respectively on treatment with concentrated H_2SO_4, a new constitutional formula has been proposed for morphine. The suggestion is based on a study of the behaviour of morphine, codeine, indole and proteins containing indole groups towards formaldehyde or acetaldehyde and concentrated H_2SO_4. The conclusion arrived at is the same as that of Bucherer as a result of his investigation on the action of sulphites or morphine.

Space representation of Nitrogen in Organic Ammonium compounds by means of a single tetrahedron.—*By* P. Neogi.

It has been shown in this paper that neither Van't Hoff's cubic, or Willgerodt's double tetrahedron or Bischoff's pyramid representation of nitrogen in organic ammonium compounds explains recent experimental results which are satisfactorily explained by representing nitrogen as a single tetrahedron with the negative radical attached to it but in the secondary sphere of action. The following considerations necessitate the adoption of the single tetrahedron formula :—

(1) the discovery of isomers of the type $[Me_3N.OR]OR_1$ and $[Me_3 N.OR_1]OR$ which shows that the fifth valency is different from the other four,

(2) the number of isomers of the type Na_3bx, Na_2bcx and Nabcdx predicted by the existing configurations never conforms even remotely to experimental results which, however, *invariably* agree with the deductions from the single tetrahedron formula,

(3) the number of isomers containing one asymmetric carbon and one asymmetric nitrogen atom predicted by the existing formulæ is absurdly large whilst the tetrahedron formula would yield only four optical isomers which have been obtained experimentally by Harvey and others,

(4) the discovery of optically active amine oxides O : Nabc by Meisenheimer is a crucial proof of the validity of the tetrahedron formula,

(5) the fact that substituted pyridinium and quinolinium compounds have not been resolved whilst tetrahydro quinolinium derivatives have been resolved is satisfactorily explained by no formula other than the tetrahedron formula,

(6) the passage of trivalent nitrogen to pentavalency is explained by supposing that trivalent nitrogen in the amines has a plane configuration which, when passing to the pentavalent condition assumes an " in-tetrahedron " configuration and then passes on the complete tetrahedron when pentavalent,

(7) Owing to the fact that $\overset{III}{N} . \overset{III}{N}$ is more stable than $\overset{V}{N}. \overset{V}{N}$, compounds containing two pentavalent nitrogen atoms joined together are not stable and therefore have not been resolved. The non-existence of such compounds is not due to interference as supposed by B. K. Singh. Compounds containing two asymmetric nitrogen atoms separated by and joined to carbon atoms have been obtained as isomers. In this case as we have two *separate* pentavalent nitrogen atoms not joined together, they are capable of existence in the same compound. As a matter of fact carbon is almost unique in forming chains of carbon atoms joined together—a property to which the existence of organic chemistry is due and which is not shared by other elements.

It is to be noted that the idea of a tetravalent configuration for pentavalent nitrogen is to be found in some of the writings of Werner, Meisenheimer and several others. But the systematic development of this configuration for nitrogen have hitherto been wanting so much so that so late as in 1915 Cohen, Marshall and Woodman (Trans Chem. Soc., 1915, 887) wrote that " the choice of space formulæ for nitrogen at present lies between the double tetrahedron arrangement of Willgerodt and the pyramid formula of Bischoff " and that in 1916 Singh has been seeking the explanation of the inability of two pentavalent nitrogen atoms in interference deducible from the pyramid formula. It has been the purpose of the paper to show systematically that the single tetrahedron formula explains far more satisfactorily a much larger number of experimental facts than the existing formula for nitrogen.

Potential of the Nitrogen Electrode.—*By* R. VENKATESWARAN.

The decomposition voltage of normal hydrazoic acid is 1·29 volts, the E.M.F. of polarisation being presumably due to hydrogen and nitrogen. An attempt was made to prepare a nitrogen electrode by coating a hard glass tube with a film of platinum, platinising this, and immersing the tube in a N_{100} solution of N_3 ions, through which carefully purified nitrogen was bubbled. The potential of this electrode was measured against a

decinormal calomel electrode, and was found to be slightly (about ·08 volts) negative to hydrogen, an impossible value for a nitrogen electrode. It was proved that the nitrogen was not electromotively active, the measured potential being due to the platinum metal in a solution containing a minute concentration of Pt ions. Subsequently the potential of a platinised platinum anode, at which nitrogen was being evolved electrolytically from a N. Sodium azide solution was measured with an auxiliary calomel electrode during the passage of the polarising current. Results were obtained indicating that the potential of a nitrogen electrode in a normal solution of N_3 ions is very near to that of the bromine electrode. It is also evident that the nitrogen set free during electrolysis of sodium azide differs from ordinary nitrogen, since the latter is electromotively inactive.

Section of Zoology and Ethnography.

President—MR. K. RAMUNI MENON, *M.A., Professor of Zoology, Presidency College, Madras.*

(*Presidential Address.*)

In opening the proceedings, the President disavowed any intention of giving an introductory address and said :—

However, as President of the Section, I think I may say that I note with pleasure the increasing interest in zoological investigations evinced in this country as evidenced by the rapidly-increasing output of zoological work in which the Indian Museum takes such a predominant part, and incidentally also by the number of zoological papers being presented to the Section this year. When the people of this country really and seriously require original work to be done in zoology as in other subjects, I feel confident that workers will be forthcoming in zoology no less than in other subjects. In the meantime, those who by their position or by inclination are interested in zoology will cordially appreciate such additional opportunities and facilities as are thrown up by the ever-advancing wheels of administration, and we may uugrudgingly welcome the fact that in the newly established University of Mysore zoology forms one of the principal subjects of study. With the ample backing of the Mysore Government, I hope we may reasonably anticipate a fruitful and prosperous future for zoological research in this city. There is one other point. You will notice that this year our section comprises not only zoology but ethnography as well. Personally, I am not inclined to regard this as an ideal grouping, and I have no doubt that as workers in ethnography increase, a separate Section will have to be created for them. But for the present, the arrangement is the most practicable, and, in view of the obvious relation of physical anthropology to zoology, is a logical one. While we zoologists may have little to offer at present which will interest ethnologists, I am sure we shall be benefited by being associated with a subject of such surpassing human interest.

Recent Experimental Enquiries concerning the so-called "Renal Portal" System.—*By* W. N. F. WOODLAND.

In the rains of 1915 I ligatured the renal afferent veins of three toads (*Bufo melanostictus*). They all recovered from the operation and for some weeks at least fed well and appeared to be perfectly healthy. One died exactly six weeks after the operation, another I killed eight weeks after the operation, and the third had lived twelve weeks when I killed it. In all three toads, when examined post-mortem, the renal afferent veins were found to be still well ligatured (no new veins having formed), the kidneys

were perfectly healthy and had much increased in weight (the ratio Weight of kidneys/Weight of body was much greater in these toads than in normal toads), though the renal arteries had not increased in size. In all three cases however (even in the three-month toad which appeared when killed to be in perfect health, eating well, active and shedding its skin on the night previous) the liver was in a diseased condition, large cysts having developed in it, which condition was apparently solely due to the large amount of additional venous blood poured into it viâ the anterior abdominal vein. Had it been possible to divert the blood excluded from the renal afferent veins into the main venous system instead of into the liver capillaries, the three toads would have remained in perfect health.

In 1916 I repeated these experiments and obtained similar results. In the case of one toad which lived nearly six weeks, I analysed the urine while the animal was in good health (active and feeding like normal toad) and ascertained that the urine secreted each day was normal in quantity (total nitrogen estimation) as compared with that of normal control toads.

In 1915 I also ligatured *one* renal afferent vein in each of four toads, one surviving three and a half weeks and another eight weeks after the operation; the other two I killed after eight weeks and twelve weeks respectively. In all cases the kidneys were together slightly larger than in normal toads and were *equal in size to each other*, the kidney with the ligatured vein sometimes being larger than the other.

In 1915 and 1916 I cut out a piece of the anterior abdominal vein in a number of toads and found that they either died, or, after a certain number of days, re-formed a new abdominal vein; in no case did the toad assume a healthy appearance and remain devoid of an anterior abdominal vein.

The conclusions I drew from those results were that the arterial supply of the kidney is the only essential one, the kidney not making use of the venous blood supplied by the renal afferent or other veins.

In 1916 I devised and successfully carried out a number of decisive perfusion and other experiments on the frog (*R. tigrina*) kidney. The most important experiment I performed (repeated twelve times) was to anaesthetize a frog with ether, remove all the brain except the cerebellum (thus preserving the respiratory centres), ligature the renal afferent vein (which was cut behind the ligature) and pelvic vein of one side and run in normal saline (with or without a trace of urine) through a cannula inserted into the coeliaco-mesenteric artery and connected with a perfusion bottle. The frog continued to breathe well for several hours, thus ensuring the oxygenation of the saline solution traversing the renal arteries and the rest of the body. The ligature of the pelvic and the cutting of the renal afferent of the same side posterior to the ligature ensure that the pressures in the two iliac arteries are approximately equal and therefore that the pressure in the unligatured renal afferent bears much the same relation to the pressure in the renal arteries as exists in life. The ureters were carefully dissected out and inserted each into a glass collecting tube. The results of these experiments were that during the time that the ligatured renal afferent vein remains empty and the pressure in the kidney of that side (the "arterial" kidney) is therefore less than the pressure in the other kidney, the secretion of the arterial kidney is less, but when the ligatured renal afferent vein becomes distended with the perfusion solution from the renal arteries, then the secretions of the two kidneys are produced at an equal rate, though the urine of the arterial kidney is more dilute than that of the normal kidney.

Urine obtained after ligaturing the veins carrying blood to the kidney, and causing increased pressure in the renal arteries by ligaturing the coeliaco-mesenteric and the two iliacs in nitrogen contents (no perfusion fluid used), was found to be as strong as normal urine.

In another series of experiments I connected the iliac artery with the renal afferent vein of the same side by means of a glass U tube and so

caused a flow of arterial blood and oxygenated saline to traverse the venous channels of the kidney: urine was produced abundantly while the renal arteries were intact, but *on ligaturing these the secretion entirely ceased.*

The conclusions to be drawn from all the above experiments (to be published in full in due course) are (1) that *toads and frogs can live with their kidneys solely supplied by the renal arteries*, the venous supply to the kidneys being unessential; (2) that although the venous supply to the kidney maintains blood pressure in that organ, yet since this function can readily be taken on by the penetration of the arterial blood into the venous sinuses of the kidney, it is not an essential feature of the venous supply; (3) that experimental facts prove *that the arterial capillaries of the kidney open into the venous sinuses of the renal venous meshwork ("renal portal system") after the former have supplied both the Malpighian capsules and the tubules, and that therefore the venous blood does not come into contact with the excretory cells in a functional capacity, i.e.* the venous blood never penetrates under normal conditions into the arterial intertubular plexus or the glomeruli; (4) that the fact that in my perfusion experiments the urine of the arterial kidney was more dilute (in nitrogenous contents) than the urine of the normal kidney (*i.e.* with a venous supply) is to be accounted for by the further facts that in the normal kidney of these experiments the venous blood supply contained more diuretic in solution (due to addition of waste products from the leg tissues) than the arterial blood (diluted by perfusion saline introduced into renal arteries) and therefore diuretic diffused from the venous sinuses in the kidney into the arterial intertubular capillaries, thus making the arterial blood in these capillaries strong in diuretic; in the arterial kidney this venous supply was absent and the arterial blood consequently weaker. Since under normal conditions the arterial blood contains as much waste nitrogenous matter in solution as the venous, no such diffusion would occur, and the urine produced by an arterial kidney is as strong as that produced by a normal kidney (as proved by the non-perfusion experiments quoted above and by the experiments of Bainbridge, Collins and Menzies). Evidence from all sources therefore proves that the renal venous meshwork ("renal portal" system) is, under normal conditions, devoid of junction.

A revision of the Indian Species of *Meretrix*.—*By* J. HORNELL.

The genus *Meretrix* contains a number of estuarine species. Those living in the waters of Continental India are exceedingly variable in regard to colouring, shape, or both combined. Ignorance of this fact has led to great taxonomic confusion and to the undue multiplication of species. There are really only two good species living on the Indian mainland, *viz. M. meretrix* and *M. casta.* The former is very variable in colour, particularly when young, but is stable in size and shape when mature; the latter varies with differing environment, resulting in the production of several varieties and local forms. The forms found in the east coast estuaries of *M. casta* are true to type within narrow limits; while those meretrix living on the west coast vary greatly and present several varieties, which, however, are all connected by a perfect series of intermediate variations. The author gives a key to the Indian Species and varieties of *Meretrix.*

A new Protozoan cause of widespread Mortality among Marine Fishes.—*By* J. HORNELL.

Several theories have been advanced to explain the annually recurring mortality among fishes and crabs on the Malabar and S. Canara Coasts. Among these may be specially mentioned (1) Suffocation by excessive

mud in suspension, (2) influx of putrid water from rivers into the sea. None of these theories can be regarded as satisfactory. The result of certain investigations made on the west coast shows that the mortality is to be directly traced to the immense development of Euglenid swarms in inshore waters after the rains. The water at this time is highly charged with dissolved organic matter and thus favours the growth and multiplication of Euglenids. The effect of the vast superabundance of Euglenids is to render the water thus contaminated unsuitable for the existence of all kinds of fishes, crustaceans, and molluscs. Many of these animals are thrown ashore moribund or dead; great quantities of them are stupefied and die and putrify in the sea. The foul water thus produced extends seawards under favourable conditions and thus spreads the area of the plague and causes further mortality among fishes. The Euglenid concerned differs from typical fresh-water Euglenids. The author gives details of its structure and behaviour.

A method of cutting sections of the wings of Insects.—*By* E. H. HANKIN.

The wing is first placed in a solution containing ammoniacal silver nitrate, Rochelle salt, and alcohol. After a time varying from a few minutes to a few hours the wing is thereby blackened owing to the deposit of a thin film of metallic silver. The wing is then washed in 50% alcohol and placed in rectified spirit. It is then embedded in jelly. The jelly used is a strong agaragar containing eight per cent of hyposulphite of soda. The portion of the lump of jelly containing the wing is cut into ten slices of equal thickness by means of a Gillette razor blade. The slices are threaded on to a wire in the right order after trimming to a convenient size. They are then placed in a half per cent solution of tartaric acid in 70 per cent glycerine for 24 hours. The acid causes precipitation of finely divided sulphur (by decomposition of the hypo) in the jelly which is thereby rendered white and opaque. The sections therefore are seen in black on a white background. The sections are mounted in a cell containing gelatine jelly.

A number of wings of different kinds of insects treated in this way were exhibited.

Anthropological notes on the Eurasians of Indo-Portuguese descent in Cochin.—*By* L. K. ANANTAKRISHNA IYER.

Introduction.—Origin and History of the Community. *Habitat.*—Intermarriage of the Portuguese with native women in former times. *Marriage customs.*—In former times and at present. *Inheritance.*—Religion. *Funeral customs. Occupation. Dress, appearance, &c.* The paper was illustrated with lantern-slides.

The Occurrence of Iridocytes in the Batrachian larva, *Microhyla* ornata (Boul.).—*By* C. R. NARAYAN RAO.

The striking feature in the colouration of the larva of *Mycrohyla ornata* and *M. rubra* is the occurrence of a bright dorsal metallic (golden) band and of silver brilliance on the sides and the ventral surface of the abdomen, and probably used as a warning advertisement in consequence of the floating habits of the tadpoles. The dorsal band is formed of very fine plates of guanin or iridocytes while the silver brightness is due to the reflecting tissue or argenteum, which is not guanin kalk. On chemical analysis, it is found that the substance of iridocytes and argenteum is identical with that met with in the iridescent tissues of fishes.

The only organ that bears both chromatophores and iridocytes is

the lung whose homology with the air bladder of fishes is corroborated on the chemical side.

On the habits of the Hilsa (*Clupea ilisha*) and their artificial propagation in the Coleroon.—*By* B. Sundara Raj.

1. *The Hilsa.*—Otherwise called the Indian Shad, is a valuable food-fish in India.

2. *Distribution of the Hilsa.*—Extensive. In peninsular India it is known to occur only on the east coast. The apparent success of the Madras Fishery Department to introduce the fish into the Ponani river (Malabar) in 1909.

3 *Size.*—Adult males attain a length of 30 to 35 cm. and are smaller than adult females which reach a length of 35 to 40 cm.

4. *Habits.*—A knowledge of the habits essential for pisciculture—A summary of all that is known of the habits of the Hilsa and my own observations at the Lower Anicut (Coleroon).

5. *Effect of weirs on the Hilsa fishery.*—Dr. Day's condemnation of weirs and his prediction (1869) of the extermination of the Hilsa. Sir F. Nicholson's reply (1909). The conclusion that Hilsa since the loss of their upstream spawning grounds have probably found suitable places for breeding in streams unfettered by weirs.

6. *Histry of the Hilsa Hatchery in the Coleroon.*—Day's proposal (1868) to construct fish passes abandoned as impracticable. Mr. Wilson's suggestion (1908) that pisciculture is the only satisfactory and final solution of the Hilsa problem. The construction of the Coleroon Hatchery the first of its kind in India (1909) and a description of the Hatchery.

7. *The Method.*—Mr. Wilson succeeded in hatching Hilsa eggs in 1908 and 1909—Particulars of the process as determined by a series of experiments conducted by me at the Hatchery last August, when about 10 million fry were successfully hatched out.

8. *Conclusion.*—The practicability of artificially impregnating and hatching Hilsa eggs has been established beyond doubt. The rearing of the delicate fry has not yet been attempted and remains yet to be done.

Notes on some South Indian Cecidomyiids causing galls in grasses.—*By* Y. Ramachandra Rao.

Paddy is subject to a disease known variously as "Anaikombu," "Thandeethu," "Kodu" and "Silvershoots". It manifests itself by the formation of a long hollow shoot instead of the normal ear-head, and is a source of loss to the ryot.

The silvershoot is a gall caused by a Gall-fly : *Pachydiplosis oryzae*: the eggs are laid on the plant, and the maggots that hatch seek the growing tips of the shoots and cause the formation of the tube-like gall. The maggots pupate inside and in about 6 days transform into flies, which emerge through a hole bored through at the tip.

Various wild grasses at Coimbatore and in several places in the Bellary, Kurnool and Godavari Districts were examined in the attempt at finding the wild host plant of the Paddy gall-fly. Galls were noticed in the following grasses :—

1. *Panicum fluitans*, } The same fly attacks both the grasses:
2. *Panicum punctatum*, } life-history fully studied.
3. *Cynodon dactylon*: A collective gall is formed: life-history studied.
4. *Ischœmum ciliare*: Coimbatore: Fly reared.
5. *Panicum stagninum*: Godavari: fly reared and probably identical with the paddy fly.
6. *Paspalum scrobiculatum*: (wild variety): Fly not reared.
7. *Andropogon annulatus*: Fly reared.

8. *Andropogon Schœnanthus*, } Flies not reared.
9. *Apluda varia.* }
10. *Iseilama spp*: 2 Flies at Palur.
11. *Ophiurus corymbosus*, } Flies not reared.
12. *Oryza sativa* (wild variety.) }
13. *Ischœmum pilosum*: Galls noted in black soils in Bellary District: flies reared. These are probably the galls forming the subject of a paper on "Galls on an Indian grass" by Mr. Boodle: Kew Bulletin No. III, 1910.

Except in the case of *Panicum Stagninum*, the flies bred out proved to be distinct species, each restricted to a single grass.

Numerous parasites attack these gall-insects and fall into 2 groups: In one the chalcids,—the wasps lay their eggs directly on or near the maggots. In the other—the Proctotrupids—the wasp searches out the eggs of the gall-fly and deposits eggs therein, as exemplified by *Platyojaster oryza.*

Indian Tadpoles.—*By* N. Annandale, *and* C. R. Narayana Rao.

The tadpoles of most of the frogs and toads that inhabit the plains of India are now known and have been or will shortly be described in detail, but in a considerable proportion of the species that live in the Himalayas and the Western Ghats little has yet been discovered about the life-history. In a paper to which this may be regarded as a preliminary note we hope to give full descriptions of the larvae of about one half of the Batrachian Anura of India proper and Assam.

Those tadpoles that have been found in the mountainous districts of the Indian Empire are of special interest on account of the adaptations to environment they exhibit. Most of their peculiarities are correlated with life in rapid-running water in which it is important that they should not be carried away by the current or if carried away should float lightly on the surface. In some tadpoles from the Himalayas and other mountain regions situated to the east of India (for example, the larvae of *Rana afghana*) we find a large sucker or adhesive organ formed on the ventral surface of the abdomen, while in others the lips are modified to perform the same function. This is the case, for instance, in the tadpole of *Bufo asper*. Other larvae from the same streams (those of several species of *Megalophrys*) live in small crannies at the edge but are provided with an enormous funnel-shaped structure that surrounds the mouth and can open like an inverted umbrella in such a way as to support them floating on the surface with the tail held vertically. The tadpole of *Rana beddomei*, which lives in the hills of Western India, is modified for an amphibious existence by the early outgrowth of the hind limbs and the degenerate character of the fin-membrane of the tail; it can thus skip away over damp rocks at the approach of a flood. Some allied species from the same streams have lost the horny teeth characteristic of the larvae of most families of Anura, but in this case we do not know what the modification means.

The Indian tadpoles of still water mostly belong to two types: (1) tadpoles in which there is no mouth-disk and no horny beak or teeth and in which the spiracle is situated in the mid-ventral line, and (2) those that have a fleshy disk surrounding the mouth, with a horny beak in the middle and armed with transverse row of minute horny teeth; in such forms the spiracle is situated on the left side of the body. Indian tadpoles of the former type all belong to the family Engystomatidae, while those of most of the Ranidae and Bufonidae belong to the latter. In the Ranid genus *Oxyglossus*, however, there is no mouth-disk, while in certain species of *Rana* the horny teeth, as already noted, are absent.

At first sight adaptive modifications in structure frequently mask taxonomic features in tadpoles. A good instance of the kind is to be found in the genus *Megalophyrs* of the family Polobatidae. Most of the larvae of this genus as yet known have the peculiar mouth-float briefly described above and also remarkably long and slender tails, but the tadpole of *M. hesseltii*, which lives in Burma and the Malay Region, is of a much more normal type. One *Burmo-Malayan* species of Microhyla (*M. annectens*) of the family Engystomatidae, in which the mouth-disk is usually absent, has, on the other hand, a funnel-shaped mouth-float analogous to that of tadpoles of the peculiar Megalophrys type, though differing in details of structure.

It would thus seem that convergence often plays a more important part in the superficial characters of Anurous larvae than genetic relationship, but it is possible that in some instances the convergence has taken place in the adults rather than in the larvae and that species in which the adults seem to be related actually resemble one another because of parallel evolution rather than on account of descent from a common ancestor. On the other hand, the resemblance between tadpoles of different ancestry is often quite superficial and one finds that adaptations at first sight similar, have been produced in different lines of modification. For instance, in those Oriental species of *Bufo* in which the mouth has become a powerful adhesive organ, the modification consists mainly in a great enlargement of the lower lip, whereas in the larva of a species of *Helophryne*, an African frog of the family Cystignathidae, a superficially similar structure is produced by the equal enlargement of both lips.

It is noteworthy that a tadpole very like that of *Helophryne* but not yet assignable to any known Indian species or genus, occurs in the hill-streams of Cochin. Judging from what we know of other tadpoles, we would not be surprised to find, when the adult is discovered, that a real relationship exists.

Notes on the Anatomy of a Double Monostrosity in the Chick. —*By* D. R. Bhattacharya.

The monster consists of two individuals, intimately connected together along their ventral side. There is, however, only a single head. There is a distinct neck, vertebral column, limbs and limbgirdles, to each individual. The hinder region of the medulla Oblongata divides to form two spinal cords. The sterna of the two individuals do not meet together as was to be expected, but the ribs of the adjacent sides of the two individuals coalesce to form a sternum, which thus takes a lateral, instead of a ventral position. Each sternum, therefore, is contributed to, in its formation, by both the individuals. The body-cavities of both the individuals coalesce, and lie in the space situated between the two sterna and their attached ribs. Most of the internal organs, especially those which are common to both the individuals, lie in this joint body-cavity. There is only a single set of the following organs common to both the individuals :—The heart, lungs, the greater portion of the digestive canal from the gullet down to the middle of the ileum, the trachea, bronchi, liver, spleen, pancreas, etc. The single heart supplies both the individuals. Each individual, however, possesses a pair of kidneys, rectum, cloaca and bursa Fabricii.

An Instance of Mutation *Coccus viridis* (Green) a Mutant from *Pulvinaria psidii* (Maskell).—*By* K. Kunhi Kannan.

Saltatory variations in green bug. The typical green bug has seven antennal segments. In Mysore it was so when it first appeared but the number has been reduced to three except in specimens found on a single plant in Bangalore. In Ceylon the number is seven. In Uganda there

are two forms, one typical the other for some time regarded as a sub-species. but recently given specific rank. In Java there are two forms, one round, the other long—both showing loop more or less but with 8 antennal segments instead of 7. These therefore are structurally nearer *P. psidii.* The specimen from Lagos is said to agree with the typical form.

Similar antennal variability in *P. psidii* specimens showing loop, without ovisac but with the eggs laid directly beneath the body have been found. The variability in the same direction is explicable only on the hypothesis that the forms of green bug are derived from *P. psidii.* This hypothesis was discussed.

Section of Botany.

President—RAO BAHADUR K. RANGA ACHARI, *M.A.*, *L.T.*, *Government Lecturing Botanist, Agricultural College, Coimbatore.*

Tinnevelly Fauna.—*By* K. RANGA ACHARI.

The flora of the Tinnevelly District may be considered to be an epitome of the whole of the Madras Presidency, as almost every feature of which is represented within this area. There are two distinct botanical regions in this district—the eastern and the western.

The eastern region is a vast plain extending from about the base of the hills to the shore, and it supports a vegetation more or less similar to the plants growing on the eastern side of the Presidency from Ganjam to Cape Comorin, although there may be well defined areas with different sets of plants, and hence distinguishable one from the other, while at the same time we meet with plants of very wide and even distribution. The sea-coast abounds in sea-weeds, littoral species and sand-binding plants, and the vegetation towards the inland is of the stunted type, as this region is very dry and hot on account of its peculiar geographical position.

The western region consists of the southernmost end of the Western Ghauts separated from the long chain by the Palghat gap. This region is botanically the most interesting. The vegetation at the foot of the hills and at the lower elevations consists of mostly scrubby jungles characteristic of the Madras Presidency. Amidst these, however, occur species of plants peculiar to these regions, such as *Eugenia rubicunda*, *Anogeissus pendula*, *Alphonsea sclerocarpa*, etc. In certain places near Mundanthurai, Anonaceous species predominate, showing Malayan affinities. Four new species of plants, *Diospyros Barberi*, *Grewia pandaica*, *Aglaia Barberi* and *Farmeria indica*, were found flourishing here.

Viewed from a broad standpoint, the higher elevations of the hills in this district present the same characteristics as those of the Anamalais, Pulneys and Nilgiris, but as we proceed southwards we notice features peculiar to this district. The forests are evergreen and moist for the greater portion of the year. The species of plants, *Diotocanthus grandis*, *Hedyotis purpurascens* and *Orthosiphon comosus*, that are confined to these hills lend a charm to the landscape. There are over thirty species of plants endemic to this region and most of them are found in the southern part of the Western Ghauts. Recently two new species of Compositae, *Senecio Calcadensis* and *Vernonia Ramaswami*, were discovered. One species of *Crotalaria* and two species of *Vernonia* are awaiting determination.

The Indian Species of Iseilema Hack.[1]—*By* R. S. HOLE.

1. Existing confusion regarding the definition of the species.
2. Revision of existing definitions and key to the species.

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[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

3. Importance of a detailed study of wild species with reference to (*a*) economic questions and (*b*) the problem of the origin of species, as indicated by a study of this genus.

The Method of Inheritance of certain Characters in Rice.—*By* F. R. PARNELL.

This is a continuation of a paper given at the Science Congress in Madras two years ago.

Certain characters, there described as simply dominant, are now seen to be due to two factors. At least four factors are concerned in the various types of awning investigated.

Several types of gametic re-duplication were illustrated. These include two cases of coupling of separate factors giving a result which was previously regarded as the effect of one factor on several organs.

The Economic Significance of the Root-Development of Agricultural Crops.[1]—*By* ALBERT HOWARD, *and* GABRIELLE L. C. HOWARD.

The detailed study of the root-systems of the various agricultural crops has been greatly neglected in the past. Hitherto far too much attention has been devoted to the above-ground portion of the plant and it has almost been forgotten that a very large part of any crop consists of the root-system which is ordinarily out of sight. This omission to study the relation between the soil and the distribution of the roots is a common feature of the variety trials which nowadays form so large a part of Experiment Station work.

The object of this paper is to show that a comparative study of the root-systems of a set of varieties throws a considerable amount of light on the relations which exist between the most suitable type of crop and the soil in which it grows. The results of variety trials often become considerably clearer from a study of the roots of the various varieties tried.

For proper root development, one of the conditions necessary is good soil aeration. Now in the alluvium of the plains of India one of the most difficult things is to manage the soil so that its aeration is not interfered with by rain or by irrigation water. The crumb structure of fine alluvial soils which is so easy to produce is also readily lost under monsoon and irrigation conditions. In consequence, the soil and the roots of the crops cannot obtain sufficient oxygen and in many cases carbon dioxide accumulates. The crops suffer from lack of aeration in the soil and oxygen becomes a limiting fact r. This is the explanation we have suggested for a whole series of phenomena relating to crops on the Indo Gangetic alluvium. All the facts so far obtained fit into our aeration theory and we have come to regard the surface layer of the Bihar alluvium as a vast oxygen filter separating the atmosphere from the sub-soil water, which analysis shows is particularly poor in dissolved oxygen. All soil-aerating agencies like surface-drainage at once increase production provided the supply of organic matter in the soil is adequate. Now if this is true and if the Bihar alluvium does act as an oxygen filter we should expect to find that all the varieties which really thrive during the monsoon phase in this tract are surface rooted and that very deep rooting kinds would not do well. To some extent, a similar rule ought to hold in the cold weather (*rabi*) crops but not to quite the same extent as in these crops the rainfall between sowing time and harvest is small and during this period soil-aera-

[1] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.

tion is at its best. We have from time to time investigated this point and have dealt with some of the results obtained in the present paper.

1. LINSEED.

The Indian linseed crop falls into two main classes :—

(*a*) The large seeded, early, little branched types of the soils of the Peninsula.

(*b*) The small seeded, late, much branched forms of the alluvium of North Bihar and the Eastern Districts of the United Provinces.

Associated with these differences in the above ground characters are differences of equal magnitude in the root-systems. The linseeds of the Peninsula are deep-rooted, the branching of the tap root taking place mainly at a point about a foot below the ground level. The linseeds of the alluvium are shallow rooted ; the main tap root sending out numerous strong laterals parallel to and near the surface of the ground. It would appear that soil aeration is the dominant factor in the type of linseed grown in the two areas in which this crop is mainly concentrated. On the soils of the Peninsula, the cracking of the soil enables the moist subsoil to be aerated. On the alluvium, the roots are compelled to run near the surface so as to secure a sufficient air-supply.

2. GRAM.

The distribution of the gram crop in India depends chiefly on two factors—soil temperature and soil aeration. Gram is an important cold weather crop to the north of a line joining Bombay and Patna and is not found to any great extent on the warmer soils to the southward. In the gram tract itself, the density is greatest where the natural aeration of the soil is above the average.

That the distribution of this crop in the gram area depends on the aeration of the soil is supported by all the results obtained at Pusa. The best crops are obtained in dry years on high, well-drained soil. On stiff badly aerated plots the yield falls off and the root development is shallow. In wet years, the yield is inversely proportional to the length of the tap root.

3. WHEAT.

Very little work has been done in India in tracing the connection between the root-systems of wheat varieties and their suitability for certain types of soil. The matter, however, is being taken up at Pusa and it is possible to refer to some of the preliminary results.

Some very interesting details have been obtained on this point in connection with the distribution of Pusa 12. Pusa 12 is a deep-rooting, high-yielding variety. It was isolated from a mixture in the Botanical Section at Pusa where it was found that this type gave excellent results on the lighter wheat soils of the Experiment Station but was apt to be disappointing on heavier lands. When tried in the United Provinces however, it quickly came into favour. Excellent crops were obtained ; the size of the ears and the yield were greater than anything that had been obtained at Pusa even with the best cultivation. The soil of the alluvium of the United Provinces are more open than those of Bihar, and this deep-rooting wheat immediately responds. On the other hand, the wheat which suits Bihar best is Pusa 6, a shallow-rooted variety which does not do well in the drier wheat-growing areas of the Indo-Gangetic plain. Here the shallow-rooting is a distinct disadvantage.

4. HIBISCUS SABDARIFFA AND H. CANNABINUS.

These two species of fibre plants, which are usually sown at the break of the rains in Northern India, differ greatly in two respects—in the amount of branching and in their tolerance of moist soil conditions. The varieties of *Hibiscus Sabdariffa* are much branched plants which thrive in the wettest monsoons and show little sign of wilt. The types of *H. can-*

nabinus, on the other hand, are tall, erect plants which, when grown in the ordinary way for fibre, branch little but are particularly prone to wilt. These distinctions between the two species are correlated with marked differences in the root-systems. The main tap root of *H. Safda-riffa* is comparatively short but there is a great development of lateral roots which run parallel and quite close to the surface. The root-system is extensive but it is concentrated near the surface of the ground, and in very wet seasons leaves the soil and grows out into the air. The development of the aerial roots all over the surface of the ground was very marked in the wet monsoon of 1916. In *H. cannabinus*, the tap root is deep and the development of the laterals is not concentrated near the surface. The root-system in this species is much deeper than in the case of *H. Sabda-riffa*. The general connection between the depth of the root-system and the liability of the two species to wilt will be evident. In the case of *H. Sabdariffa*, the aeration of the roots is easy and the crop thrives even in wet years. In the case of *H. cannabinus*, aeration is more difficult and the plants are very liable to wilt.

5. Java Indigo.

Up to the present, we have considered the root-systems of crops which are either grown in the monsoon or in the cold weather. Bihar agriculture, however, has to deal with a plant—Java indigo—which is grown all the year round including the hot months of April and May. Any successful type of plant must accommodate itself to a set of soil conditions ranging from extreme wetness in the monsoon to comparative dryness in the hot weather.

Java indigo as grown in Bihar is an exceedingly mixed crop and consists of a large range of types which however fall into two main classes as regards branching—(1) bushy types which branch to very varying degrees from the base, the branches coming off nearly at right angles to the main axis, and (2) tall vertical types whose branches arise at an acute angle from the stem. These two conditions may be shortly described as the bush type and the vertical type. Running through both these classes of branching are great differences in the rate of growth and in the time of flowering. Some of the types are early; others are exceedingly late. Some grow slowly; others much more rapidly. All grades of intermediate naturally occur.

A general correspondence between the mode of branching of the stem and of the root exists in this crop. In the bushy types which branch at right angles to the axis, the lateral roots are also given off at right angles to the main tap root. In the vertical types, the lateral roots arise at an angle very similar to that in the case of the branches.

Five types of rooting have so far been distinguished including two in which most of the root-system is near the surface. These withstand the moist soil conditions of the monsoon much more successfully than the deeper rooted types.

Recent *Oxalis* Introductions to India.—*By* C. C. Calder *and* M. S. Ramaswami.

This paper records the recent spread to India of some six species of *Oxalis*, a genus which finds its highest development as regards number of species in South Africa and temperate S. W. America.

One of the number *Oxalis Corymbosa* A. Dc. has already occupied the serious attention of Australian agriculturists. It is probably of quite recent introduction here but has succeeded in establishing itself with dangerous rapidity in parts of India.

The authors call attention to its presence and cite its history in Australia as indicative of the trouble it may become to Indian Agriculturists.

The genus *Oxalis* is geographically very unstable and a discussion of the distributional history of the remaining species is prompted by their now recorded presence as wild plants in India.

In conclusion the authors call for the co-operation of systematists and others engaged in botanical pursuits in recording the arrival and the success or failure of exotics in establishing themselves, in India.

Note on a Malformation of a Pine-apple (*Ananas*).—*By* P. F. Fyson.

A malformation of the Pine-apple is described in which the receptacle had grown out laterally and bore a very large number of small flowers in an irregular formation, recalling on a large scale the Cockscomb variety of the cultivated Celosia. The tissues were found infested with an intracellular plasmodium, to which the fasciation was in all probability due.

Note on the Killing off of a True Water Plant (*Scirpus micronatus*) by a Plant of firm though moist land (*Ammania Rotundifolia*).—*By* P. F. Fyson.

Scirpus micronatus L. which forms a dense fringe round the shores of the lake at Kodaikanal has been dying off at certain depths, while growing well in deeper as well as in shallower water. Where this happens the roots are surrounded by a dense matting of thin stems and narrow leaves which though different in appearance have been traced to the Ammania rotundifolia *Ham* which grows on the adjoining bank.

Oecological Notes on the Flora of the Pulney Downs.—*By* P. F. Fyson.

Attention is drawn to certain plant associations and special adaptations exhibited.

The Inflorescence and Flowers of the Banana (Musa sapientum) and its wild relative (Musa superba).—*By* W. Burns, V. G. Mandke *and* P. J. Dhunbhura.

The paper describes a research in progress, the aims of which are :—

(1) to observe accurately the development and morphology of the inflorescence and flowers in *Musa sapientum* and *Musa superba* ;

(2) to study the phenomena of pollination and fertilisation in these species ;

(3) to study the seed production of *M. superba* and the non-production of seed in *M. sapientum.*

The *transition-leaves* that herald the appearance of the inflorescence are described and a theory put forward to account for their fewness in *M. sapientum* and their abundance in *M. superba.* Variations in the bracts both as to shape and axillary flowers are described. The various organs of the several types of flowers are described and special attention is given to the perianth and androecium. It is concluded that the flower of Musa is undoubtedly developed from the usual monocotyedonous type, and that its present form is due to (*a*) suppression of the posterior stamen, (*b*) the reduction of the two anterior members of the inner whorl of the perianth and their fusion with the three similarly reduced members of the outer whorl, and (*c*) the development of the remaining member of the inner whorl as a hood-like body.

Sections of the ovules of both species are described. The embryosac contents have not yet been clearly made out. Crosses made both ways

between the species resulted in seed production. It is proved that the banana fruit swells without pollination but that of *M. superba* does not. The influence of pollen of a red variety did not show when used to fertilise a yellow variety of banana. The origin of the edible pulp is stated. An interesting variant of the banana, producing in normal circumstances 25 "hands," is described and its possible heritability discussed.

Observations on Pollination in *Alysicarpus*.—*By* K. CHERIAN JACOB.

The whole genus *Alysicarpus* possesses in the flower an interesting explosive mechanism for the sudden discharge of pollen into the air or on an insect-visitor. The Indian species of *Alysicarpus* can be divided into two groups, one with glumaceous calyx enclosing the corolla and the other with small calyx reaching to only about half the length of the corolla. *A. rugosus*—a representative of the glumaceous calyx group explodes its mechanism only when visited by *Nomia oxybeloides*. Unexploded flowers do not set fruits at all. *A. vaginalis*—a representative of the small calyx group—is capable of exploding its mechanism without the help of any external agency and throws a cloud of pollen upwards showering the same on the flowers of the neighbouring plants. The usefulness of this adaptation in securing cross-pollination is evident from the fact that this species possesses a gregarious habit. In fact, in a patch of ground 7 inches in diameter, the branches of 9 different plants could be traced and one square foot of ground covered by the plant showed on an average about 90 different inflorescences.

So, in the above we have an instance of a common plant which ensures cross-pollination by the spontaneous explosion of its flowers and without the help of any external agency.

The irritability of the Bladders in *Utricularia*. II. Structure and Mechanism.—*By* T. EKAMBARAM.

1. The structure of the irritable hairs is described and compared with those of aldrovanda.

2. Part of the ridge surrounding the mouth is shown to act as a spring hinge which draws down or pushes up the valve.

3. The positions assumed bv the valve before and after irritation is shown to be due to a difference in the dimensions of the two layers of cells that make up the valve. The mechanism is explained.

4. The function of the margin is also partly explained.

5. The hungry condition of the bladder is brought about by all the tissues becoming turgid.

6. The result of irritation is taken to be a momentary loss of turgidity in all the tissues.

Variation in some Himalayan liverworts.—*By* S. R. KASHYAP.

Four species of thallose liverworts are described showing a considerable degree of variability.

1. *Targionia hypophylla*. Already worked out by the writer and also by Miss O'Keefe. (New Phytologist, Vol. XIII, Nos. 6 and 7 and Vol. XIV, Nos. 4 and 5). The chief features of interest here are :—(*a*) the presence of antheridia on the usually described disc-like ventral shoots, also on shoots having more or less well-developed wings and lastly even on the main shoot in the form of a dorsal cushion. (*b*) The different degrees of development of the teeth in the involucral valves. In some specimens they are well-developed throughout the whole margin of the valves, in others feebly developed or quite absent on the greater part of the margin.

2. *Aneura Indica* St. *n. s.* Great variations in habit and the shape of the dorsal epidermal cells. The plants may be thin loosely attached to the substratum, very slightly branched or simple, leading through various transitional forms to those which are firmly fixed to the soil, have thick lobes and are very much branched. The dorsal epidermal cells may be quite flat, slightly convex externally, dome-shaped, or conical and distinctly papillate with distinct spaces between them. These variations in habit and structure seem to depend on climatic conditious in which the plant grows.

3. *Metzgeria pubescens* (Shrank) Raddi. The usual form found in Britain has ten or eleven epidermal cells on each side of the midrib and the plants are pinnate. In some plants found in Mussoorie by the writer the midrib was very narrow and had only four epidermal cells on each side and the plants were distinctly dichotomous. In some other specimens found by the writer on the Chamba-Pangie road about 10,000 ft. above sea level, the midrib had six or seven cells on each surface and plants showed a tendency to pinnate branching owing to great development of one branch. Those variations are interesting as the two characters are generally thought to be constant.

4. *Anthoceros Himalayensis* Kashyap. The plant was described by the writer from Mussoorie (New Phytologist, Vol. XIV, No. 1). The sterile plants were narrow, closely attached to the soil and bore tubers either marginally or ventrally or both. Specimens are found in a place near Simla, under water showed broad thin lobes dividing dichotomously and entirely without tubers. These plants differed from the typical specimens of *A. Hymalayensis* so greatly that they could be referred to that species only after some more specimens had been found in a moist place midway between the two above-mentioned forms in habit and bearing embedded tubers.

The effects of Physical and Climatic conditions on the distribution of plants in Mysore Malnad.—*By* M. K. Venkata Rao.

Introduction. Literature-abstract. The area comprising the Mysore Malnad.

Physical conditions :—

(1) Variations in elevation. (2) Exposure to sea breeze. (3) Long and narrow valleys. (4) Winding rivers and streams. (5) Evergreen forests. (6) Loose and pervious soil.

Climatic conditions :—

(1) Variations in rainfall. (2) Prolonged drought. (3) Variations in temperature. (4) Fog and humid atmosphere. (5) Heavy winds.

Effects. (*a*) Direct :—

(1) Reduction in size of leaves. (2) Presence of aromatic oils. (3) Poor quality of timber. (4) Uniformity of distribution and similarity of species. (5) Intense colouration of flowers. (6) Occurrence of Xerophytic vegetation. (*b*) Indirect :—

(1) Occurrence of forests in patches in protected valleys. (2) Proportionate increase of climbers and epiphytes. (3) Comparative absence of thorny plants. (4) Abundance of Ferns and mosses. (5) Comparative rarity of fresh-water species of algae except Diatoms. (6) Saprophytic fungi and Parasites plants due to decomposing vegetation. (7) Very wide distribution of seeds and fruits.

Conclusion.

Spike Disease of Sandal.—*By* L. Coleman *and* M. S. Narasihman.

This serious disease of one of the most valuable Indian Forest Products was first noticed near Fraserpet on the Coorg-Mysore frontier in

1899 but was probably in existence for several years prior to that date. Within the past sixteen years about three-fourths of the sandal area in Coorg has become infected. In Mysore it has appeared in most of the sandal areas in Mysore District and in several areas of Hassan and Bangalore Districts. In Madras Presidency it has also appeared in a large number of sandal areas in Salem, Coimbatore and Trichinopoly Districts.

It is difficult to estimate the losses due to the disease but there are indications that sandal to the value of 5 lakhs of rupees are being destroyed annually. If as appears likely the disease continues to spread to areas which have hitherto remained free, sandal as an economic product will practically cease to exist unless we can discover some efficient means of combating the disease.

The chief outward symptoms are (*a*) a reduction in size of the leaves, (*b*) shortening of the internodes, (*c*) disturbance in the growth periodicity leading to growth throughout the year, and (*d*) death of haustoria and end roots. Inner structural changes are few and unimportant but there is one typical internal symptom, *viz.* the deposition of large quantities of starch in parenchyma of twigs and leaves.

The paper considers the question of starch deposition and shows that there is a disturbance in the translocation indicated by a reduction of diastatic activity in diseased leaves. Whether there is any alteration in the rate of carbohydrate formation in the diseased leaves as compared with healthy ones is under investigation. The fact not heretofore sufficiently emphasized, that leaves showing outward evidence of spike are invariably pale in colour, would point to a decreased carbohydrate formation rather than to an increased one.

The question of the communicability of the disease is discussed and the results of experiments in which twigs from spiked trees were grafted on to healthy trees are given. These show conclusively that the disease is communicable as in a large number of cases the disease was communicated in this way. Injection of an aqueous extract from diseased leaves into healthy trees has, up to the present, given no result.

A number of other plants have been found attacked by diseases showing similar symptoms. In the case of one of these plants, *viz. Zizyphus oenoplia*, it has been found possible to communicate the disease by grafting just as in the case of sandal spike. The question of the possibility of communicating the disease as it appears in one of the species attached to a healthy plant of another susceptible species is under investigation.

Possible methods of infection in the light of our present knowledge are also discussed in the paper, but our knowledge of the disease is still too incomplete to formulate definite conclusion on this point.

On the Endophytic Nitrogen-fixing Bacteria in *Lemna minor* (L) & *L. polyrrhiza* (L).—*By* M. O. Tirunarayanan.

Two nitrogen-fixing organisms—*Bacillus radicicola* and *Azotobacter*—have been recognised as living inside the tissues of *Lemna*, and also to occur in large numbers on its upper surfaces. In cultures on Mannite Maltose-agar the two kinds of colonies develop and have been indentified as the distinct colonies of these two microorganisms. Both of these bacteria fix atmospheric nitrogen and thrive in nitrogen-free media. In the tissues, they live in association with endophytic *Nostoc*, similar to such associations in *Cycadaceae* and also in *Azolla* and *Anthoceros*. Besides this, the bacteria seem to occur in certain special cells bounding on internal airchambers, which contain a Zooglea of bacteria and are free from nucleus and chloroplasts. But they have not yet been recognised in the tissues of *L. minor*.

On the Nitrogen-fixing Bacteria inside Root-galls caused by Eel-worms.—*By* M. O. Tirunarayanan.

Nodules caused by eel-worms, in roots of *Benincasa*, *Momordica* and *Musa* contained bacteria. These were isolated and by the colonies obtained on different media, stabs and streak-cultures, the peculiar motility, staining reactions, and capacity to fix atmospheric nitrogen, have been identified as belonging to the species of *Bacillus radicicola.* They flourish in nitrogen free-media.

These plants have been healthy. Instead of being harmful, the nematode attack is perhaps beneficial, because, through its agency, there is established an association between these bacteria and the plant, and the plant may profit by the presence of these bacteria in the same way as *Alnus Eleagnus*, &c.

Section of Geology.

President—Mr. C. S. Middlemiss, *C.I.E., M.A., F.A.S.B., Geological Survey of India.*

(*Presidential Address.*)

Complexities of Archaean Geology in India.

There is no doubt that if one impartially regards the trend of geological theories concerning the oldest rocks, known as the Archaeans, in India, there is apt to arise a feeling of bewilderment. One gets puzzled and perhaps upset by the fertility and versatility in explanation indulged in by geologists when once they give their imagination a free rein in the domain of these very difficult rocks. I am also bound to admit that very much the same sort of bewilderment may readily take possession of one when, instead of theories, one surveys the prime cause of those theories, namely the rocks themselves. The science of geology, alas, does not seem to get any simpler, clearer or more straightforward as it grows older!

Here in Mysore, and one may say in Southern India generally, there are certain aspects of the Archaeans about which a great change of opinion appears to have arisen during the last 12 years or so—as the geology of to-day has gradually unfolded itself from earlier beginnings.

One has but to refer to the beautifully executed geological map of Mysore, on the scale of 1″ to 8 miles, recently issued by the Mysore Geological Department, and to the solutions of some of the Archaean problems as concisely presented in the very interesting "Outline of the Geological History of Mysore" by Dr. Smeeth, Director of the Department of Mines and Geology, and which, I believe, is the substance of his address before a previous meeting of this Congress, to recognise that many geological problems, regarded as delightfully simple in the old days of Indian geology, now bear new and startling interpretations, and that some rock terms (or the theoretical conceptions underlying them) have had to be scrapped and cast into the melting pot, to emerge—something quite different.

To be a little more explicit, let me call your attention to the case of rocks known as the Dhárwár system, one of the original homes of which is Mysore. In the earlier days of Indian geology (though not so long ago after all) they were described in modest terms as hornblende and chlorite schists, quartz iron-ore rocks, quartzites, conglomerates, etc., and they were regarded mostly as metamorphosed sediments, or at least as such associated with epidiorites of effusive igneous origin. They were supposed without question to overlie the "fundamental gneiss" and to have

been deposited upon it with an unequivocal unconformity marked by a conspicuous conglomerate at or near the base,—in fact to be younger than that gneiss, to have been folded up on top of it, faulted in places, denuded in places, and so left in their strip-like basins, as presented to our view to-day.

But things have gone apace with the energetic and versatile members of the Mysore Geological Department, and now the main order of rock succession has long ago been implicitly, and more recently formally, reversed; the Dharwars becoming the oldest rocks in Mysore, whilst for nearly every one of the rock members of that system, including even the limestones, conglomerates, quartz iron-ore schists and lastly the quartzites, an igneous origin of some sort is now seriously championed. If one reads through the Records of the department for the last ten years or so one constantly comes across remarks by Messrs. Wetherell, Slater, Jayaram and others to the above effect. For instance: "The quartzites are probably all of igneous origin and belong to different relative periods of formation, just like the various other acid members of the series" or "From the general evidence obtained it is satisfactorily clear that the true character of these conglomerates is autoclastic and not sedimentary. The most sedimentary-looking grit, arkoses, and fragmental rocks appear to be highly altered lavas and tufaceous deposits and not metamorphosed true sediments."

I might go on quoting in the same strain for some time, but I will content myself with one more example from Dr. Smeeth's "Outline" where, speaking of the quartzites, he says: "Others, entirely quartzose, are occasionally found to exhibit intrusive contacts with adjoining rocks, whilst others of a later date penetrate the subsequent granitic gneiss and even pass from the gneiss into the schists. There can be little doubt that many of these quartzites are crushed and recrystallised quartz veins and quartz-porphyries and possibly felsites, and it is at least open to question whether we have any which are genuine sedimentary rocks." Whatever outsiders may think as to the reliability of these conclusions, there can be no doubt as to the unanimity with which they have been advocated. Indeed Dr. Smeeth in one of his annual reports appears to be rather tired of the "hornet's nest" that he has raised in the form of the "constant transference of previously imagined sedimentary conglomerates to autoclastic conglomerates" and he sighs for "some one to find a simple satisfactory sedimentary conglomerate with nicely rolled water-worn pebbles"!

Such a revolution of thought, quietly and apparently unanimously undergone, by the members of the Mysore Geological Department, regarding the origin and relative age of these rocks and the series of mineral and physical transformations through which they have gone, must be very disconcerting to the ordinary geological student. It must be extremely perplexing I should think to all who have occasion to refer to the Records and Memoirs of the Department.

To myself, I must own to its being very unacceptable at least in its entirety; for it must be remembered that in the early nineties I spent a considerable time mapping the areas of Salem and Coimbatore, and in association with Mr. F. H. Smith saw something of the Dhárwárs as they appear tailing off into long-drawn-out strips and patches in the northern part of these districts. My opinion then formed of those strips and occasional wider patches is expressed in an MS. report written at that time, and I may perhaps quote a portion of this. I then wrote:—

> "As regards the interrelations of the Dhárwárs with the gneissic system, it is evident that the general appearance of the Dhárwárs, their distinctness of texture structure and composition, and the way they lie in continuous bands enfolded among the gneisses, are indications in every way presumptive of the former being the younger formation and that it comes in normal sequence above the gneiss:

although since their formation they have been subjected to earth movements which have acted on them both alike, and caused their present disposition (as indicated by outcrops and foliation dips) to be generally inconclusive one way or the other.

Some few exposures (sections they can hardly be called) are, however, so strongly in favour of the received views concerning this relation that they must be mentioned here. Mr. Smith has described, and I also myself saw, one locality in the valley N.N.W. of Maharajgadi, where a certain flattening out of the Dhárwárs and a bending round of their strike appeared to point to the existence of a slightly shallow synclinal of them upon the gneiss. In another locality a few miles east of Krishnagiri and a little west of Sundanapalli Mr. Smith states that the exposure of the Dhárwárs seems to be that of a rough basin resting on the gneiss though the dips are seen to be much disturbed. Also round about Maradapalli the Dhárwárs are seen to rest directly on the upturned gneiss. Other places visited by myself to the north of Barugur show the same thing—in the usual imperfect way in which sections are exposed in this part of the country. I may instance the hill 1½ miles E. by N. from the Barugur travellers' bungalow, the upper parts of which are all Dhárwárs apparently resting on a platform of the gneiss beneath; and also an exposure north of Neralkotta where a somewhat sudden change from the one rock to the other has all the appearance as of the Dhárwárs lying upon the top of the gneiss.

The search for actual junction sections was, however, for a long time unproductive. At last the little crag on the side of the hill E.N.E. of Barugur, and easily recognised in the distance by its darker colour, yielded such a section: but we were not prepared for the extraordinary nature of the section revealed. It is about 5 yards long, and at the base of it the hornblende biotite gneiss, typical of the Hosur and Krishnagiri plateaux, is seen. Above there are Dhárwárs of the lower-most or epidiorite type, whilst between the two is a zone composed of a matrix of the hornblende-biotite gneiss among which is distributed an irregular assortment of fragments of Dhárwárs. We might describe the arrangement as a zone of the gneiss containing included blocks of the Dhárwárs. The fragments are of all sizes from a few inches across to several feet. They are roughly angular, and many of them are composite blocks, being built up of a number of smaller fragments—the result without doubt of a large block having split up into pieces *in situ*. With everything else in favour of the Dhárwárs being the younger formation, here is an appearance that I think the majority of observers would say showed that the intrusive gneiss was younger than the Dhárwárs!

But before committing ourselves to this last conclusion, let us sum up the arguments for the contrary: —

(1) The work of the older observers has been held to show that the Dhárwárs are a younger formation resting with complete unconformity and a great conglomerate on the gneisses.

(2) The Dhárwárs of the Salem District here referred to are directly continuous into those of Kolar, and must certainly be the same.

(3) The mode of occurrence of the Dhárwárs is as strips among the gneiss, not the reverse. Also there are no veins or veinlets of the gneiss among the Dhárwárs.

(4) Almost universally in the gneiss there are long trains of similar inclusions at other places where no bulky outcrop of Dhárwárs of sufficient magnitude to be mapped is known; and these trains of inclusions frequently coalesce in one or other direction into unbroken strips in the gneiss of from 1 to 3 feet wide.

Thus the evidence is conflicting. Whilst general conclusions that have great weight are in favour of the younger age of the Dhárwárs, the particular section given above might be held to prove just the contrary.

Only, I think, by looking upon the Hosur gneiss as a rock that has passed through (it may be) several vicissitudes of solidification and plutonic remelting without ever having developed much intrusive motion as regards the formations above, can the above conflicting testimony be harmonised."

Such was the somewhat inconclusive view I had of the Dhárwár strips in Salem at that time. I was prepared for a liberal interpretation of the nature of the unconformity at their base, but no suspicion directed against the then received explanation of their sedimentary or sub-aerial origin had entered my thoughts.

Well, gentlemen, the new interpretation of this Dhárwár problem by the Mysore Geological staff has now been before us for some years, and presumably it is being constantly tested on the ground, and in due course the full data in support of it, accompanied by accurate drawings, photographs and detailed plans on an adequate scale will likewise be laid before us and before the geological world. It is a matter of considerable importance that these (especially the drawings and photographs) should be provided, for so far I think I am right in saying that no graphic representation of these extraordinary wholesale transformations of granites quartz-porphyries and other igneous rock types, into schists, conglomerates, limestones and quartzites, has as yet appeared from the pencil of any of those responsible for the statements. Otherwise I am afraid there will always be a feeling of doubt and questioning in the minds of many.

Meanwhile in this short address it is no part of my desire or intention to question them. Geology is not a science whose results can be settled as by a debating society. I confess, however, that I should very much like to question the rocks themselves, once more again,—to go straight to the fountain-head, so to speak, and help myself to the arguments and facts at first hand—but unfortunately one cannot be in more than one place at a time, and I have other duties to attend to.

It has, nevertheless, occurred to me that, whilst one may perhaps be permitted to suspend judgment as regards these South Indian rocks, until the long awaited data, in full, are kindly vouchsafed us by the Mysore geologists, it might not be amiss to take into consideration certain other areas of Archaean rocks that have recently been under exploration by the Geological Survey of India, and see if they show a similar or different *tendency* in the matter of interpreting the facts discovered. Many of these have come under my own observation, and I have some claim therefore to speak about them at first hand. In the Central Provinces, in Rajputana and in Idar State in Bombay surveys have recently been in progress on Archaean rocks. Of these areas, I have personal knowledge of the last two and particularly of Idar State.

In Idar I have found myself up against a great many difficulties in trying to elucidate the genesis of the wonderfully complex rock systems of the Aravallis and Delhis. Dr. Fermor, Mr. Fox and the late Mr. Burton have similarly had no easy task in the Central Provinces.

As illustrating just one aspect of these difficulties I may perhaps briefly refer to the question of the calcgneisses of those areas. It is a peculiar feature of the rocks of this class in India—whether we consider those of Coimbatore, Vizagapatam, Burma, or the recently explored calcgneisses of the Central Provinces and Idar, that (on the supposition that they are metamorphosed calcareous sediments of some sort) they never show any simple and straightforward passage into unmetamorphosed strata. The converse of this proposition is so generally recognised as true that it hardly requires any remark. It is notorious that all through the great Vindhyan and other old series such as the Cuddapahs and Karnuls

the extremely natural and normal calcareous and other sediments show no passage into anything resembling what are ordinarily known as crystalline limestones, calciphyres and calc-gneisses.

Hence, failing any trace of a sedimentary origin, there have not been wanting efforts to explain the limestone element of these rocks as having been derived, by the action of carbonic acid in solution, from pyroxenic ortho-gneisses, which by assumption are regarded as magmatic. I need only refer to the classical work of Judd and Barrington Brown on the Burma crystalline limestones (Phil. Trans. Roy. Soc., Vol. 187 A, p. 205) and to the earlier interpretations of my colleague Dr. Fermor in the case of the Central Provinces calciphyres (Rec. Geol. Surv. of India, Vol. XXXIII, pp. 168-171). Quite recently, however, both my two colleagues in the Central Provinces, Dr. Fermor and Mr. Burton, have returned to the more simple and straightforward conclusion that not only the calc-gneisses but also the crystalline limestones have been derived from a banded series of calcareous sediments of varying degrees of purity, combined with *lit-parlit* injection of acid magma. This will be seen from the quotation which I now reproduce from the General Report for the Geol. Surv. of India for the year 1914-15.

"Mr. Burton in his progress report, 1912-13, regards the crystalline limestones as derived from sedimentary limestones of various degrees of purity, and accepts the formation of mica, pyroxene, amphiboles, and chondrodite, as due to the re-crystallisation of the original impurities in the limestone, with pneumatolytic addition of fluorine; but the felspar in the quartz-pyroxene gneisses he regards as in part of pneumatolytic origin. He thus favours in the main the recrystallisation hypothesis. During the past season's work (1913-14) Mr. Burton had the opportunity of devoting further attention to these calcareous rocks as developed in the Balaghat district. This led to an interesting development of ideas, so that whilst Mr. Burton still supposes that the calc silicate minerals of the calc-gneisses (calc-granulites) were in part derived from original impurities in the calcareous sediments, he lays stress on the fact that the predominant felspar is microcline with varying amounts of orthoclase, plagioclase being present only in small amount or altógether absent. He deduces that this microcline was derived from the associated orthogneisses during folding, when the latter became refused and attained the condition of an igneous magma containing gases and pneumatolitic agents. The felspars both of the calc-gneiss and of the ortho-gneiss show quartz inclusions (*quartz de corrosion*), and this, Mr. Burton thinks, indicates that the calc-gneiss and the ortho-gneiss must have crystallised under the same conditions of pressure, indicating that the calc-gneisses are really mixed gneisses which have re-crystallised under plutonic conditions.[1]"

In the case of the Idar State examples, I may perhaps be allowed a few words of description, since the observations and data are of my own collecting, and have not been hitherto mentioned from this point of view.

The rocks of this category, there, consist of crystalline limestone and calc-gneiss, of various kinds within certain well-defined limits. The whole set is thoroughly well banded after the manner of any Archaean schist or gneiss, and it is penetrated almost everywhere by a very constant set of lenticles, lenticular bands, branching dykes and occasionally anastomosing granite aplite veins and occasionally by more massive intrusions of biotite-hornblende granite, known as the Idar granite. It is generally roughly equidimensional granular aggregate of frequently large

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[1] During the present field season (1914-15) Dr. Fermor has accepted Mr. Burton's idea that these rocks are mixed gneisses and both he (in Chhindwara) and Mr. Burton (in Balaghat) have arrived at the conclusion that the hybridism has, at least in part, been effected by the *lit-parlit* intrusion of the calcareous rocks by an acid magma. In Chhindwara, however, labradorite is as abundant as microcline in the calc-gneisses.

amounts of calcite, pyroxene (diopside), quartz, orthoclase and microcline with a little plagioclase, biotite and sphene. Occasionally there is a little graphite and pyrite, scapolite, wollastonite, zoisite and minute pale garnet grains (grossularite), with large developments of idocrase (vesuvianite), at one or two places.

These rocks occupy a considerable area in the northern part of Idar, and, though they may merge into another division of the Aravallis, the amphibolite limestones (which I must not stop now to describe) in one direction and into a non-calcareous biotite gneiss in the other, they display no signs anywhere of a passage into unmetamorphosed ordinary limestones, etc.

I would call your attention, however, particularly to two interesting varieties of the calc-gneiss as there developed. one consisting very largely of diopside, wollastonite and sphene and with no free quartz or calcite, and another variety appearing close up against the Idar granite in which great masses of idocrase rock have been developed as a close contact-aureole of that granite. And I would further remark that in another series of Aravalli rocks lying some 8 miles away from the nearest calc-gneiss outcrops, and consisting of a thick series of generally but slightly altered slates, grits, calcareous, siliceous rocks and simple limestones, whose sedimentary origin in my opinion is beyond doubt, I have been able to trace in the proximity of another intrusion of the Idar granite, an exactly similar development of minerals as just referred to, the pyroxene (diopside) and the wollastonite and sphene making up the greater part of the rock in a finely granulitic condition and with large prisms and rounded grains of idocrase. There are many other less salient features of this undoubted sedimentary series that further link it up with the calc-gneiss in an indirect way that I might adduce, but, until the full facts are published, the above may perhaps be accepted as being a very strong argument supporting the theory of the origin of the calc-gneiss by metamorphism of normal impure calcareous sediments which (all interstratified with each other in endless repetition) comprise dark slates, grits, such as are used for grindstones and hones and ordinary soft limestones.

As regards, the calc-gneisses then (being one example of the Archaean complex in Northern India), it is necessary to emphasise the fact that, though they have been a standing puzzle for a long time in India, and though they still offer many attractive problems to work out concerning the serial and particular development of the several minerals, the general tendency of the opinion of workers on them is to regard these rocks as having originated by metamorphism (coupled perhaps with hybridism) from a sedimentary series. I must pass over here the particular, supposed, pneumatolytic influence of the injected granite aplite veins, as accounting for the hybrid features of these very interesting rocks in order briefly to refer to one other aspect of the Idar Archaeans in reference to the great overlying masses of the Delhi Quartzite.

However much one might dispute the sedimentary origin of the Dharwar quartzites, it would be a bold man who would declare the enormous thicknesses and extension of these frequently well-bedded, current bedded and sometimes even ripple-marked quartzites (known all through Rajputana and many other neighbouring districts and states as the Delhi Quartzite) to be anything else than a sedimentary rock—in spite of the fact that it has generally become completely recrystallised.

And yet these rocks, as developed in Idar and as traced into that State by perfectly continuous exposures over an enormous area of country, exhibit the most incongruous relationships to the underlying Aravallis. In their broad aspects they at first suggest an unconformable overlie similar to the proved unconformity seen in more northern sectlons such as Alwar; but, examined in detail, this is not found to hold, no characteristic synclinal trough arrangement ever manifesting itself, and the ridges and ranges of these rocks possessing plagioclinal strikes as regards the general direction of the ranges and outcrops up against the Aravallis at

their bases. They are frequently extremely sheared and broken up into platy layers near any Aravalli junction, against which they frequently plunge with dips at right angles to the strike of the juxtaposed Aravallis. The whole aspect of the Delhi Quartzite in this area is of enormous ridges, sections and blocks of quartzite strata floundering about as it were in a viscous Aravalli sea. Furthermore there are in certain places actual junctions shown, where stoping of Delhi Quartzite blocks of from one foot or less to several yards in width can be seen as it were in actual operation, and where the whole of these blocks and many also of the half disintegrated basal layers of the Delhi Quartzite have begun to get detached and ready to break away under the stoping operations of the underlying biotite gneiss And all of these blocks and loosened lower strata, it is important to notice, are in their interstices crowded with many of the typical calc-gneiss minerals, *e.g.* wollastonite, calcite, diopside and grossular garnet—these contact-developed minerals weathering out at the surface of the blocks and leaving a spongy, cavernous layer behind. Chaotic and irregular as is the junction between these two systems in Idar, I am not sure that the parallel arrangement in Ajmer of the same Delhi quartzites to the underlying calc-gneisses (chiefly amphibole epidote gneiss there) does not eclipse it. Last cold weather in the company of my colleague Mr. Heron I had the privilege of seeing near Sendra some of the most amazing relationships between these two formations, which, however, would require diagrams to illustrate them satisfactorily and for which I fear I have not time to trouble you with now, as we have a large number of papers to get through this morning.

Before concluding, I should say that the impressions I have gathered in Idar with regard to these and other phenomena are on the whole in favour of calling largely on the processes known as plastic deformation and dynamometamorphism for an explanation of very many of these peculiar results. I am inclined to picture to myself that below a certain level underground, such as may well have now been exposed by uplift and denudation in the roots of this old Aravalli mountain chain, processes of the above category may well have brought about in the Delhi Quartzite, in the Aravallis below, or along the junction line between them, very great and powerful metamorphosing actions that have simulated magmatic stoping and assimilation, that have probably reduced much rock in certain areas to the condition of aqueo-igneously fused rock-pulp, and that have culminated in the production of gneisses. It is even allowable to suppose that they may also have caused the inception among them of intercrustal veins, lenticles and dykes of aplite and other pegmatitic variants, after the manner advocated by A. C. Lane, quoted in Daly's "Igneous Rocks and their Origin," p. 370, and named by him "selective solution." In that reference it is said that: "During intense regional metamorphism, specially of the dynamic kind, deep-seated rocks, charged with much interstitial water, may reach the relatively low temperature at which minerals corresponding to the quartz-felspar eutectic go into solution with the water and other volatile fluxes. Such small, locally generated pockets, lenses or tongues of fluid may be driven through the solid country rock for an indefinite distance; subsequently to crystallise with the composition and habit of the true batholithic derivatives. It is thus quite possible that these particular rocks, though truly magmatic, have had no direct connection with abyssal injections."

In other words, it seems to me that from what may once have been two unconformable systems, such as the Delhis above and the Aravallis below, one may have had generated by plastic deformation and dynamic metamorphism the appearance of a complete eruptive unconformity, separating a lower gneissic from an upper quartzite series. And if that be granted, then it is obvious that the great march of events here in these northern rock areas can only be understood as being the exact reverse of that which the Mysore Geological Department are advocating in the case of the not dissimilar position in Southern India.

I do not propose to go further than this, and it is certainly not my intention in any way to suggest that the Mysore Department should immediately proceed to revise their conceptions regarding the origin of the rocks of their own extremely interesting country; but I do urge that all the *pros* and *cons* in the case should be very carefully and patiently considered, as I have no doubt that they certainly will be.

Chamberlin and Salisbury have written as follows in their Geology, p. 429 (1905), under the heading of "Completion of the Rock Cycle":—

> "The crystallising processes of metamorphism are fundamentally similar to the processes by which rocks crystallise out of magmas, only in the first case the work is done chiefly by the aid of an aqueous solution, while in the second it is done through the mutual solution of the constituents in themselves where water was but an incident. If the heat factor in metamorphism be sufficiently increased, aqueous solution may actually grade into magmatic solution through various degrees of softening and melting, and the cycle of changes be closed in upon itself."

Consequently, it seems to me, that in dealing with any rock that appears to be of doubtful igneous or magmatic origin, it is above all necessary in these days to ascertain in which direction the cycle of change is moving. To put the matter bluntly—an apparent ortho-gneiss with its contemporaneous veins may quite as well be an intensely metamorphosed sediment with pegmatites formed in it by 'selective solution' as it may be the extreme, foliated or otherwise modified, representative of a granitic, gabbroid or hybrid abyssal injection.

Notes on the Origin of the Living Molluscan Fauna of the Indian Ocean, with reference to Former Geological Times. —*By* E. Vredenburg.

The object of this paper is to show that most of the genera and species characteristic of the Indian or Indo-Pacific region at the present day have originated in that same region in former geological times; and that, in previous geological periods, the fauna of the Indo-Pacific region differed from that of the Atlantic and Mediterranean very much in the same manner as it does at the present day. It also shows that during certain intermittent periods of wider marine extension, when there was a more direct communication between the Indian and Atlantic regions than exists at present, there were *some* exchanges between the two faunas, but that there is no evidence of any important migration either in one direction or the other: the slight dilution of one fauna with the other being quite insufficient to obscure the well-marked faunistic differences of the two regions.

A preliminary note on the Origin of Wolfram-bearing Quartz Lodes in Tavoy District, Lower Burma.—*By* J. Coggin Brown.

These notes are tentative results obtained up to the present time, and the author invites criticism of other workers on similar deposits. The wolfram deposits have been proved to originate from quartz lodes connected by pegmatites, aplites, etc., with granite masses penetrating the ancient sedimentary series known as the Mergui series. The granite occasionally contains tinstone and molybdenite, and the pegmatite dykes and quartz veins contain tungsten, tin, molybdenum, bismuth, iron, copper, arsenic, lead and zinc minerals.

The author criticises adversely Dr. Bleeck's theory concerning the wolfram and tin lodes of Tavoy, especially as to the presence of a distinct "mineral zone," a wolframite-cassiterite-columbite zone and the presence

of tourmaline introduced by pneumatolitic processes from the intrusive granite. The author also gives other arguments illustrating the magmatic segregation theory—pegmatitic or aplitic—of the formation of the lodes, as contrasted with the theory of Bleeck of their formation by mineral solutions and pneumatolysis. In the case of the wolfram and cassiterite quartz veins, of which the pegmatitic origin is not so clear, it seems reasonable to regard them as a hydro-thermal phase of pegmatites.

A Revised Classification of the Gondwana System.—*By* G. DE P. COTTER.

An attempt is made in this paper to sub-divide the Gondwana System into series and stages on the lines laid down by the International Congress of Geology, and to determine the European equivalents of each stage. The Maleri stage has been separated from the Kota stage; the former has been placed in the Trias, while the latter remains in the Oolitic. Evidence is brought forward to show that the Panchet stage of Raniganj is lower Trias. The upper Trias is represented by the Maleri stage, and the Rhaetic by the *Thinnfeldia odontopteroides* beds of South Rewah, to which a new stage name, the Parsora stage, is given. The Damuda series are shown to be Permian, and not partly Trias, as Koken supposed. The relationships of the Maleri to the Parsora stage are doubtful; the author paid a visit to South Rewah to determine which was stratigraphically above the other, but no definite conclusion was arrived at. He suggests, however, that the Parsora stage is very possibly the upper of the two. The Umia stage is no longer placed in the upper Jurassic, but in the lower Cretaceous, in accordance with the work of Kitchen.

An account of the Sub-division of the Deccan Trap Series in the neighbourhood of Narayanganj, Mandala District, Central Provinces.—*By* K. A. K. HALLOWES.

The author, in continuation of the work of Fermor and Fox in the Chhindwara District, gives a short account of his sub-division of the Deccan Traps in Mandla District. The separation of the boundaries of particular flows was principally effected by the aid of vesicular surfaces, green-earth horizons, intertrappean limestone and chert and by the terraces due to the above. Eight different flows have thus been distinguished, which also are found to possess minor differences of texture and composition; all of them being either basalts or dolerites with varying amounts of olivine, serpentine, chlorophaeite and palagonite in addition to the ordinary minerals of the Deccan Trap. He discusses the origin of some of the palagonite, the varying specific gravities of the flows, their silica content and their other physical characteristics.

On the application of Cochineal Stain on Calcite, and Aragonite.—*By* S. DATTA.

The author details a further set of experiments in continuation of those described by him in a paper before the Indian Association for the Cultivation of Science in September 1916, on the staining of these same minerals by means of aniline black, as a means of distinguishing them.

On the Occurrence of Limburgite in British Baluchistan.—*By* H. DAS GUPTA.

The author describes a limburgite from the Deccan Trap of Baluchistan, characterised by a smaller amount of the phenocrysts of olivine as

compared with those of augite, and the presence of felspar microlites in the groundmass. $SiO_2=40{\cdot}73$ per cent. According to the "Quantitative Classification" the position of the rock is III. 6. 4. 4, and the term *Hamandunose* has been proposed for the subrang. The presence of felspar in the groundmass is discussed and it is suggested that a very large section of the rocks now known as limburgites is very closely allied to the picrites.

Corundum and its Occurrence in Mysore.—*By* L. SUBBA RAO.

After a brief reference to the origin of the word *corundum*, the author proceeds to describe the economic value of the mineral and states that, though corundum is the richest and purest of the ores of aluminium, the cost of the mineral compared with that of Bauxite presents a real difficulty in the way of using the former for the manufacture of the metal. The paper then goes on to describe the crystalline form of the mineral. Three twinned crystals are described as specially deserving of mention. Two of them are of the cruciform type and the third represents prism of the second order and rhombohedron combined on the prism of the first order as the composition plane, the twin thus giving rise to a curious monoclinic appearance. The paper then refers to certain samples of corundum occurring at Kupya and Doddrei in Mysore where this mineral, which is generally considered unalterable, is found to be surrounded by a greenish material which the author makes out to be *margarite*. The author discusses the nature of this alteration and cites Professor Judd's statement that conditions must exist in the earth's interior under which chemical change of this mineral does take place. The paper next proceeds to a consideration of emery and its occurrence in Mysore. After stating that mineralogically emery is simply a mixture of corundum and magnetite and that its value as an abrading agent depends upon the proportion of the former constituent, the author mentions a locality in Mysore where corundom crystals are found enclosing grains of magnetite arranged in peculiar patterns as stellate figures, etc. and gives it as his opinion that such occurrences are to be considered as merely instances of emery.

The paper concludes with a short note on the origin of corundum and states that its occurrence in Mysore well illustrates the processes of segregation and metamorphism. In many cases, says the author, it is of undoubtedly metamorphic origin and in others it is the direct result, in place, of basic igneous masses. According to the author, the corundum in Mysore Province can be divided into two main groups:—(1) those in which corundum is associated with basic rocks intruding into the surrounding gneisses and (2) those in which it is associated with acid rocks intruding into the older amphibolites; and examples are given from Mysore Province to illustrate each type of occurrence.

Lectures.

Three public lectures were delivered:—

"The Sun".—*By* C. MICHIE SMITH, ESQ., *C.I.E.*, *B.Sc.*
"Soaring Flight".—*By* Dr. E. H. HANKIN.
"Explosives".—*By* F. L. USHER, ESQ., *B.Sc.*

On the opening day there was a general discussion on "Scientific Libraries in India" with Colonel Sir Sydney Burrard, K.C.S.I., R.E., F.R.S., in the chair, whilst on the last afternoon there was a discussion on "The Future of the Indian Science Congress" presided over by the President.

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Section of Physics and Mathematics.

President:—Dr. S. K. Banerji, D.Sc.

Presidential Address.

On the Cyclones of the Indian Seas and their Tracks.

Ladies and Gentlemen,

I thank you for the honour you have conferred on me by electing me President of your Section of the Congress. I am however fully conscious of my incompetency and my only wish at this moment is that the honour had fallen on abler hands. My recent stay at Simla for six months afforded me unique opportunities for studying some of the features of the Cyclones of the Indian Seas. Partly for this reason and partly for the fact that being an East Bengal man, the devastation which the cyclone of September, 1919, caused in that tract of the country made a profound impression on me, and perhaps the incident being so recent may be quite fresh in your mind too, I thought that the "Cyclones of the Indian Seas" ~~may~~ form a suitable theme for my address to-day.

Apart from all these considerations, the Norwegian meteorologists have quite recently introduced some new ideas of the origin and development of cyclones at the boundary between equatorial and polar air in middle latitudes and the subject has excited so much interest that it seems worth while to review our knowledge of the cyclones that usually form in the Bay of Bengal and the Arabian Sea, their development, movement and decay in the light of present knowledge. A large amount of information respecting these storms has been collected by the India Meteorological Department, their behaviour has been systematically studied, their tracks have been plotted, and the results of investigation have been published in a series of publications [1] of the Department. There has

[1] See Elliot's 'Handbook of Cyclonic Storms in the Bay of Bengal' and his 'Cyclone Memoirs.' See also the 'Meteorological Atlas of the Indian Seas,' the 'Climatological Atlas of India' and the 'Indian Monthly Weather Reviews.'

scarcely been a meteorologist, whether here or in other countries, to whom the process of generation of storms, their maintenance and movement have not afforded a fascinating subject for study. As a result several theories have been advanced of which two, namely, the 'counter-current theory' and 'the convection theory' have for a long time excited the greatest controversy.[1] Data, especially the 'upper air,' are wanting to enable us to put either of these theories to a confirmatory test. The fundamental difference between the tropical and the extra-tropical cyclones has been a source of perplexity even to the keenest meteorologist. Opinions have been expressed that the extra-tropical cyclones should be explained by the counter-current theory and the tropical by the convection theory. But cases are known when the tropical cyclones by moving in higher latitudes have become extra-tropical in character and it is doubtful whether we should have one theory for all cyclones or whether we should have one particular theory to explain tropical cyclones and a different theory for extra-tropical cyclones. There are, however, reasons for believing that counter-currents having their origin in differences in temperature over large geographical areas initiate the conditions that give rise to the system of gyrating winds; that the condensation of water vapour supplies the energy necessary to maintain them through considerable periods of time. In the Indian Seas when a steady current is blowing over the country as well as the seas, very few storms are formed except in the north of the Bay. For instance, when the northeast monsoon current is steadily blowing during January, February, and March no storms are developed either in the Arabian Sea or the Bay of Bengal. So also when the south-west monsoon currents assume a steady state in the months of July, August and September, cyclones of any severity rarely form either in the Arabian Sea or in the Bay of Bengal except in its north. It is during the transition periods when the north-east monsoon currents change to south-west in the months of April, May, and June, and the south-west change to north-east in the months of October, November, and December, that the weather over the Indian Seas attains an unsettled state and dangerous cyclones develop both in the Arabian Sea and the Bay of Bengal. Whether during such a period of unsettled weather, counter-currents actually play an important part in the initiation of the cyclones is a question which should naturally engage one's attention. In the months of July, August and September, the trough of low pressure running parallel to the Himalayan range frequently comprises a considerable area over the north of the Bay of Bengal. A general

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1 See the discussion in *Nature*, November, 1920, to March, 1921.

uniformity of pressure prevails over this area and conditions become favourable for the formation of storms of slight or moderate intensity. Here, again, whether this extension of the trough of low pressure is an effect of counter-currents, which under favourable conditions may initiate storms, will require investigation. With a view to understand the behaviour of the storms, that usually form in the Indian Seas, known under the general name of tropical cyclones, it will facilitate discussion if some of the observed facts [1] respecting these storms be stated here in brief:

1. A fully developed tropical cyclone consists of a vast whirl of rapidly moving air currents surrounding a calm and relatively small centre of vortex.
2. The distinction between tropical and extra-tropical cyclones consists mainly in the following:—

(*a*) The isobars of the tropical cyclone generally are more symmetrical and more nearly circular than those of the extra-tropical.

(*b*) The temperature distribution around the vortex of the tropical cyclone is practically the same in every direction, while about the extra-tropical it is very different.

(*c*) In tropical cyclones rains are torrential and more or less equally distributed on all sides of the centre while at sea; but while inland, rains are usually heavier on the side where the rain-bearing winds first enter the cyclonic system; in extra-tropical cyclones rains usually are much lighter and very unequal in different quadrants.

(*d*) Tropical cyclones have calm rainless centres while the extra-tropical rarely shows this characteristic whirl phenomenon. Calm centres are characteristics of only the well-developed tropical cyclones; the smaller storms especially those of the rainy season do not present well defined calm centres.

(*e*) Tropical cyclones are most frequent during summer of the hemisphere in which they occur, while the extra-tropical are most numerous during winter.

(*f*) Tropical cyclones often move to higher latitudes, where they assume, more or less completely, the character of the extra-tropical; the extra tropical on the other hand never invade the region of the tropical nor assume its distinctive characteristics.

(*g*) The fall of pressure of the tropical cyclone generally begins with the violent winds; in the extra-tropical it usually begins much sooner.

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[1] Humphreys' 'Physics of the Air,' pp. 173–175 (1920).

(*h*) The tropical cyclone has no anti-cyclonic companion; the extra-tropical usually has, to the west.

3. The diameter of the tropical cyclones varies very greatly. Near their origin some storms may be no more than 50 miles across, while others when well developed may have diameters of 200 to 1000 miles.

4. The direction of the surface wind is spirally at an angle of about 30 degrees, roughly, to the isobars, counter-clockwise (in the northern hemisphere). At an elevation of only 700 to 800 metres the inflow is supposed by some to cease, although there is no good evidence for believing that the height is only 700 to 800 meters, and above this level the circulation is outward. These horizontal motions necessitate a correspondingly strong upward component around the vortex or inner portion of the storm, and a slower downward component over a much greater surrounding area.

5. The wind velocity in a tropical cyclone varies greatly from one storm to another, and even more from one to another portion of the same storm. Near the centre, or within the eye of a fully developed cyclone, which may have any diameter from 5 to 50 miles or more, the wind is very light and the sky clear or only partially covered with high clouds. Away from the centre the winds often reach the destructive velocity of 90 to 100 or even 130 miles per hour but decrease in violence rather rapidly with increase of distance from the centre, dropping only to moderate winds of 20 miles at a distance of, say, 200 miles.

6. The velocity with which tropical cyclones travel varies from 50 to 300 miles per day.

In order to understand fully these and the other features of the cyclones of the Indian Seas, it will be necessary to discuss here briefly the general theory of atmospheric depressions.

On the possibility of the existence of atmospheric whirls travelling with definite velocities.

We know that a local variation in mass distribution in the atmosphere would be rapidly dispersed over a wide area and the original uniform state restored. In fact it has been proved by Professor Lamb [1] that an arbitrary disturbance of the uniform distribution of density in the atmosphere in horizontal layers would ordinarily give rise to a motion of the nature of a wave spreading out from the originally disturbed region, the velocity of propagation being of the same order of magnitude as that

[1] Lamb, "On atmospheric oscillations," Proc. Roy. Soc., LXXXIV, A, pp. 551–572 (1910). See also Harold Jeffreys, "On travelling atmospheric disturbances," *Phil. Mag.*, January, 1919.

of sound. Why then does a cyclone not spread out like an ordinary wave and disperse in an hour or two? The answer seems to be that a *cyclone* has more or less the character of a vortex *wave* the pressure and velocity distribution being such that it constitutes a stable dynamical system. That a cyclone should be considered a revolving fluid carried along in a current represented by isobars should readily appeal to those who are familiar with the hydro-dynamical theory of the permanence of vortex motion. The late Lord Rayleigh, from this hydro-dynamical conception of cyclones, derived the important conclusion [1] that if fluid had any vorticity to start with, the removal of fluid along a central axis would result in the superposition of a simple vortex, (vr = constant), upon the original rotations. Although this conclusion is exemplified [2] in tornadoes and tropical revolving storms, it seems to have excited doubt [3] so far as the extra-tropical cyclones are concerned, as the pictorial evidence of the winds in these cyclones showed a combination of translation with rotation and not a symmetrical distribution round a centre. But when proper account is taken of the translational and rotational velocities and the deviation of the winds on account of the ground, all cyclones, tropical or extra-tropical, are easily recognised as revolving fluids travelling with the speed indicated by the isobars in which they are embedded. Regarding therefore a cyclone as a dynamical system of revolving fluid, it will be instructive to consider in detail the general hydro-dynamical problem [4] in two dimensions. This problem was studied by the late Lord Rayleigh [4] a few days before his death, and we make no apology for quoting here *in extenso* the important results he obtained. Starting from the usual Eulerian equations as referred to uniformly rotating axes, we have

$$\frac{1}{\rho}\frac{\partial p}{\partial x} = \omega^2 x + 2\omega v - \frac{Du}{Dt}, \tag{1}$$

$$\frac{1}{\rho}\frac{\partial p}{\partial y} = \omega^2 y - 2\omega u - \frac{Dv}{Dt}, \tag{2}$$

where

$$\frac{D}{Dt} \equiv \frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y}. \tag{3}$$

The density ρ is supposed to be constant and gravity can be disregarded. Here x, y are the co-ordinates of a point, referred to axes revolving uniformly in the plane xy with angular

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1 Proceedings of the Roy. Soc., Vol. XCIII, (1917), p. 148-154.

2 Shaw's "Manual of Meteorology," Part IV, pp. 146-147.

3 'The Birth and Death of Cyclones,' by Sir N. Shaw, Meteorological Office, *Geophysical Memoirs*, No. 19 (1922), p. 214.

4 Rayleigh, "The Travelling Cyclones," *Phil. Mag.*, Vol. XXXVIII, p. 420 (1919).

velocity ω, (in the application to a part of the earth's atmosphere, ω is the earth's angular velocity multiplied by the *sine* of the *latitude*), u and v are the components of relative velocity of the fluid in the directions of the revolving axes, that is, the components of *winds*. We have now to define the motion for which we wish to determine the balancing pressure.

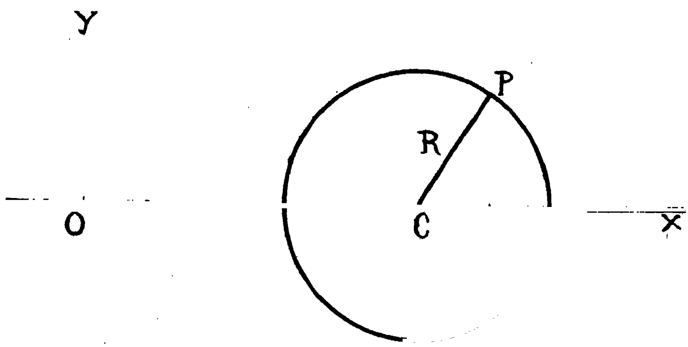

FIG. 1.

We contemplate a motion (relatively to the ground) of rotation about a centre C, situated on the axis of x, the successive rings P at distance R from C revolving with an angular velocity ζ, which may be a function of R. And upon this is to be superposed a uniform velocity of translation U, parallel to x and carrying everything forward. If initially C be at O, the fixed origin, its distance from O along Ox at time t will be Ut.

Thus

$$u = U - \zeta y,\ v = \zeta(x - Ut), \tag{4}$$

being a known function of R, where

$$R^2 = y^2 + (x - Ut)^2 = y^2 + X^2. \tag{5}$$

These equations give u and v in terms of the co-ordinates and of the time, and the values are to be introduced into (1) and (2). From the manner in which x and t enter (representing a uniform translation of the entire system) it is evident that

$$\frac{\partial}{\partial t} = -U\frac{\partial}{\partial x}.$$

We have

$$\frac{\partial u}{\partial x} = -\frac{\zeta' X y}{R}, \qquad \frac{\partial u}{\partial y} = -\zeta - \frac{\zeta' y^2}{R},$$

$$\frac{\partial v}{\partial x} = \zeta + \frac{\zeta' X^2}{R}, \qquad \frac{\partial v}{\partial y} = \frac{\zeta' X y}{R},$$

ζ' being written for $\dfrac{\partial \zeta}{\partial R}$; and

$$\frac{Du}{Dt}=\frac{\zeta' U X y}{R}-u\frac{\zeta' X y}{R}+v\left(\zeta+\frac{\zeta' y^2}{R}\right)=-\zeta^2 X\ ,$$

$$\frac{Dv}{Dt}=-U\left(\zeta+\frac{\zeta' X^2}{R}\right)+u\left(\zeta+\frac{\zeta' X^2}{R}\right)+v\frac{\zeta' X y}{R}=-\ {}^2 y\ .$$

Hence

$$\frac{1}{\rho}\frac{\partial p}{\partial x}=\omega^2 x+2\omega\zeta X+\zeta^2 X\ ,\quad \frac{1}{\rho}\frac{\partial p}{\partial y}=\omega^2 y-2\omega(U-\zeta y)+{}^2 y\ , \quad (6)$$

and on integration

$$\frac{p}{\rho}=\tfrac{1}{2}\omega^2(x^2+y^2)-2\omega U y+\int(2\omega\zeta+\zeta^2)\ R dR\ . \quad (7)$$

As might have been expected, the last term in (7) is the same function of R, as when $U=0$, but R itself is now a function of U and t.

In the case considered by Sir N. Shaw by drawing up analogy with the rigid body motion of a circular disc, having both translational and rotational velocities, (Manual of Meteorology, Part IV, p. 121), ζ is constant and may be removed from under the integral sign. Thus

$$\frac{p}{\rho}=\tfrac{1}{2}\ \omega^2(x^2+y^2)-2\omega U y+(\omega\zeta+\tfrac{1}{2}\ \zeta^2)\ \{y^2+(x-Ut)^2\}. \quad (8)$$

If $U=0$, R identifies with x^2+y^2, and we get

$$\frac{p}{\rho}=\tfrac{1}{2}(\omega+\zeta)^2\ (x^2+y^2)\ . \quad (9)$$

A constant as regards x and y, which might be a function of t, may be added in (8) and (9).

We see that if $\omega+\zeta=0$, that is, if the original terrestrial rotation is annulled by the superposed rotation, p is constant, the whole fluid mass being in fact at rest. In the strictly two-dimensional problem there is a pressure increasing outwards due to "centrifugal force." In the application to the earth's atmosphere, this pressure is balanced by the component of gravity connected with the earth's ellipticity. Thus in Shaw's case, we have

$$\frac{p}{\rho}=\text{const.}+(\omega\zeta+\tfrac{1}{2}\zeta^2)\left\{\left(y-\frac{\omega U}{\omega\zeta+\frac{1}{2}\zeta^2}\right)^2+(x-Ut)^2\right\} \quad (10)$$

showing that the field of pressure, though still circular, is no longer centred at O as when $U=0$, or even at C, where $x=Ut$, $y=0$, but is displaced sideways to the point where $x=Ut$, $y=\omega U/(\omega\zeta+\frac{1}{2}\zeta^2)$. Shaw calls this the *dynamic centre*; it is the point which is conspicuous on the weather map as the centre of the system of circular isobars.

As a case where the circular motion diminishes to nothing as we go outwards, let us now suppose that $\zeta = Ze^{-\frac{R^2}{a^2}}$ falling off slowly at first but afterwards with great rapidity. We have

$$\int_0^R \zeta R dR = \tfrac{1}{2} Za^2 \left(1 - e^{-\frac{R^2}{a^2}}\right), \quad \int_0^R \zeta^2 R dR = \tfrac{1}{4} Z^2a^2 \left(1 - e^{\frac{-2R^2}{a^2}}\right);$$

and thus from (7)

$$\frac{p}{\rho} = \text{const.} - 2\omega Uy - \tfrac{1}{4}\, a^2 \left(Ze^{-\frac{R^2}{a^2}} + 2\omega\right)^2, \qquad (11)$$

where as usual $\quad R^2 = y^2 + (x - Ut)^2$.

If gravity is introduced then since in the supposed motion no part of the fluid is vertically accelerated, the third equation of motion gives simply

$$\frac{p}{\rho} = \text{const.} - gz\,.$$

Thus (10) is altered merely by the addition of the term $-gz$.

Two questions[1] are involved. If a vortical system can persist at rest, in an atmosphere rotating with the earth, can it also persist slightly modified, with a translatory velocity U? And if so, how will the distribution of pressure in it be modified? The equations of motion give for δp an exact differential form which is integrated in (7); therefore a modified motion is possible and the first question is answered in the affirmative, in agreement so far with fact. The displacement of the pressure-system due to the progressive motion is then examined for two special cases by the formulæ (10) and (11), showing also general agreement with fact as regards displacement of the centre of the vortex. But the value of U is not determined by these considerations, which refer to frictionless fluid. When viscosity in the fluid is taken into account, the general agreement seems to remain applicable, for the velocity of translation U being uniform will not modify the viscous stresses. But, in any case, internal viscosity is negligible in meteorological problems. It is the friction against land or ocean, introducing turbulence which spreads upwards, that disturbs and ultimately destroys the cyclonic system; and the high degree of permanence of the type of motion seems to permit that also to be left out of account. The changes of

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[1] See the discussion of Rayleigh's paper by Sir Oliver Lodge, given as an appendix to the paper.

pressure arising from convection involve changes of density, which will modify the motion but perhaps slightly.

In a paper [1] on travelling atmospheric disturbances, Dr. H. Jeffreys points out that the geostrophic relation between the wind and surface pressure gradient is incapable of accounting for any variation whatever with time in the pressure distribution. All changes in this arise from those terms in the equations of motion that are neglected when the geostrophic relation is assumed. When those terms, which depend on the squares and the differential coefficients of the velocities are taken into account, Dr. Jeffreys finds that an asymmetrical cyclone only can move. He however points out that it would appear from the low speed of travel of these depressions that a simple superposition of a general pressure gradient on a rotating system must be compensated internally in some way, so as to reduce the asymmetry introduced and thus the remarkable circularity of the isobars in a cyclone is to be regarded as a condition of its slow movement. There is an apparent inconsistency between these conclusions and those of Lord Rayleigh which of course disappear if the asymmetrical system contemplated by Jeffreys be considered to be identical with the modified pressure systems given by Lord Rayleigh's equation (7).

ORIGIN AND MAINTENANCE OF TROPICAL CYCLONES.

Assuming the possibility of the existence of atmospheric whirls travelling with definite velocities, the next important questions which arise are how are these whirls originated and how are they maintained for days together? This is a matter which has excited the largest amount of controversy [2] especially with regard to the extra-tropical cyclones.

As tropical cyclones usually originate in a region of doldrums where convectional rains are frequent and heavy, and as they rarely occur closer than 5° to the equator, it has been held that both vertical convection and earth rotation are essential to their genesis. The conception underlying the idea of the origin of cyclones by the convection of warm moist air is mainly the following.[3] An approximately equal expansion of air over a relatively large area, whether caused by an increase of temperature, or vapour density, or by both, must lead to an overflow above and a corresponding surface inflow around the outer borders. Obviously the rate of volume over-

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[1] *Phil. Mag.*, January (1919).

[2] See for instance the discussion in *Nature* by R. M. Deely, W. H. Dines, Sir Oliver Lodge, Sir N. Shaw, H. Jeffreys, L. C. W. Bonacina and J. von Hann, Nov. 11, 18, 25, Dec. 2, 16, 23, 1920 and Jan. 13, March 3, 1921.

[3] See Humphreys' "Physics of the Air" (1920), p. 175.

flow at any time is proportional to the area in question, while the corresponding inflow is proportional to the boundary multiplied by the average normal component of the wind. If the area is circular with radius R, it follows that the rate of outflow above is proportional to πR^2, and the rate of inflow below to $2\pi RV$ in which V is the average radially inward component of the wind at the distance R from the centre. But as the two currents compensate each other except as modified by precipitation, it follows that V is proportional to R. Hence when the area involved is rather large, 200 miles, say, in diameter, the relatively shallow and spirally moving compensating or return current may become very perceptible. This will feed the entire rising column with excessively humid air that renders it an even better absorber than before of both insolation and terrestrial radiation and increases its rate of expansion, thus initiating perhaps a widespread condensation. If so, the latent heat thus set free, while it does not actually raise the temperature of the air, reduces the rate of adiabatic cooling from approximately 1°C to about 0·4°C per 100 metres of ascent, and thereby establishes within the rising column temperature distinctly higher than those of the surrounding air at the same level. In this way the circulation is accelerated, and thereby the rate of condensation and freeing of latent heat increased until, through growth of size, restricted supply of water vapour, and other causes, a limiting, somewhat steady, state is attained. When the conditions here described take place at some distance from the equator, the rotation of the earth deflects the inflowing air and establishes a rotation round the region of lowest pressure. From the above it is evident that the seat of activity so to speak of the tropical cyclone, is where the sustaining energy is supplied, that is, where the condensation is taking place. It is therefore to be expected that the movement of the air at this level, and not at the surface, determines the course of the storm.

We can make an approximate calculation of the ascent of air on account of convection over a circular area with a radius r of about 50 km. We take the angle of deviation of flow from the isobar to be α, V_H to be the horizontal surface velocity, and V_Z to be the upward velocity of convection. We may take convection to be uniform over the area, because the surface wind certainly decreases with the distance from the centre, perhaps not in strict proportion but not very differently therefrom. Further we require an estimate of the height to which the inflow extends and for that purpose we shall suppose that by uniform stages agreement with the gradient is reached at a height of 500 m., and that the mean velocity of inflow over the vertical distance of 500 m. is one-half of the inflow at the bottom and this being $V_H \sin \alpha$, the average velocity of inflow may be taken as $\frac{1}{2} V_H \sin \alpha$. Whence we obtain for the inward

flow $\pi rh \sin \alpha\ V_H$ and the upward convection necessary to maintain this flow is $\pi r^2 V_Z$.

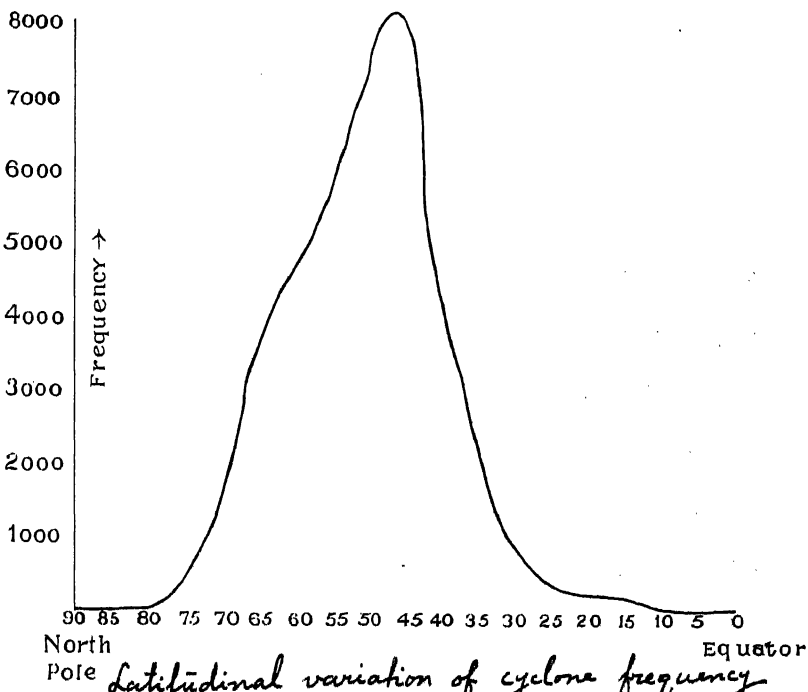
Hence

$$\pi r^2 V_Z = \pi rh \sin \alpha\ V_H ,$$

or

$$V_Z = \frac{h \sin \alpha}{r} V_H$$

$$= \frac{500}{50{,}000} \sin \alpha V_H = \frac{1}{100} \sin \alpha\ V_H .$$



Latitudinal variation of cyclone frequency

FIG. 2.

The angle of deviation varies from 10° to 60°, and assuming a mean value for it, of say 30°, and the horizontal wind 4 m/s (about 10 miles per hour) the vertical velocity works out at 0·5 m/s. This means an ascent over the whole area at the rate of 1600 m. per hour or 43 km. per day. It is therefore no wonder why convection has been supposed to play such an important part in tropical cyclones.

If, however, we take the circular area to have a radius of 1000 km., the ascent over the area will reduce to a rate of 3·6 metres in an hour, or 86 metres in a day. At this rate it

would take more than 100 days to raise the air from the ground surface even to a height of five miles. Opinion [1] has therefore been expressed that the cause of the origin of the tropical cyclone may be found in the counter-current theory as to initiation of the cyclonic centre, while the convection theory accounts for its maintenance after having started it. This conclusion has been based on the consideration that it is difficult to visualize local superheating over the wide expanses of water where tropical cyclones form and that the air in this region should rise *en masse* to a considerable height. Consequently it has been suggested that one should expect in such cases that air should rise in filaments, and the visible result would be the formation of cumulus clouds and their atttendant phenomena, such as local shower, local thunderstorms, and local vortices of a small diameter. It has further been contended that if convection were the primary cause of the origin of cyclones, we should expect to find them of maximum frequency over the calm belts of the tropics, where there is a superabundance of water vapour and relatively high temperatures over large areas. We should not expect to find, if convection were the cause, the belt of maximum frequency of cyclones (the tropical and extra-tropical all taken together) the world over in midwinter and along the border of the region of polar night.

~~*Latitudinal variation of cyclone frequency.*~~

It is however difficult to trace any of the features that have been promulgated in the latest development of the counter-current theory in the tropical cyclones. Quite a new conception of the part, that these more than local wind systems play in the formation of cyclones, is set forth by Dr. V. Bjerknes in his theory of the polar fronts and made applicable to the extra-tropical cyclones. According to this theory,[2] the successive cyclones of the temperate zones are waves on the boundary surface between the cap of polar air and the surrounding warm air masses, the corresponding boundary line on the ground, "the polar front," accordingly traversing the centres of depressions around the poles. The extreme northern ends of the warm waves coincide with the centres of low pressure and the cold waves of polar air between them constitute the moving wedges of high pressure. The cold and

[1] Edward H. Bowie, "Formation and Movement of West Indian Hurricanes," Monthly American Weather Review, April, 1922, p. 176.

[2] Proceedings of the seventh meeting of the International Commission for the investigation of the upper air, Publication of the Int. Met. Com., printed at Bergen, July, 1921. See also J. Bjerknes and H. Solberg, "Life cycle of cyclones and the polar front theory of atmospheric circulation," Geofysiske Publikationer, Vol. III, No. 1 (1922).

warm currents, which seem to be general constituents and important agents in the cyclones, are separated by relatively sharp boundaries, characterised by sudden changes in temperature, humidity and wind direction. This surface of discontinuity is supposed to supply the energy of the cyclones.[1]

Unfortunately few of these features can be traced in the synoptic charts for the cyclones of the Indian Seas. The temperature distribution, at least at the surface, in these cyclones is seemingly one of but minor variations in the several quadrants of the cyclone. As it is however not always easy to distinguish between cause and effect, it may not be quite correct to say that counter-currents have nothing to do with the initiation of these cyclones. In the month of October, the normal wind systems[2] in the Bay of Bengal definitely show a westerly current having an easterly current on its northern side. According to Sir N. Shaw[3] when such a state of things results, the two currents engage one another forthwith and a circular storm results. This is probably the reason why, helped by favourable circumstances, the storms which form at this season show a marked tendency to increase and become large and dangerous cyclones before they reach land. During the transitional periods when the conditions are so unstable in the Indian Seas it is not difficult to conceive the occasional existence of such counter-currents. But as such counter-currents will forthwith result in circular storms and as synoptic charts at regular short intervals are not available for the Indian Seas, it is not easy to express any definite opinion on this point. It may however be remarked here that Dobereck[4] has expressed the opinion that the typhoons of the China Seas are generated by counter-currents, and Bigelow, in his studies of the circulation of the atmosphere over the West Indian Waters, has shown that such currents are commonly found. During the rains, storms usually form in the north of the Bay of Bengal and generally move westwards or north-westwards. This is not difficult to understand. For during the rains when a steady south-west monsoon current is blowing over the country as well as the Indian Seas, storms can only form under very special conditions. It is only when the trough of low pressure over northern India extends far into the Bay of Bengal, that conditions become favourable for the formation of storms there. The trough of low pressure is to be conceived to have been formed by the meeting of the south-west monsoon currents steadily blowing

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1 See Bjerknes' paper on the energy of cyclones supplied by discontinuity, *Nature*, Jan. 24, 1920 and Quarterly Journal of the Royal Meteorological Society, April, 1920.

2 See the 'Meteorological Atlas of Indian Seas,' by W. L. Dallas.

3 Shaw, Sir N., Forecasting the weather, p. 286.

4 Cyclones of the Far East.

from the Arabian Sea over the country with the currents from the Bay of Bengal deflected by the Burma hills and Himalayan range and the consequent ascentional motion over the places where these two currents meet. The position of the trough will be determined by the relative strengths of the two currents. If the Arabian Sea currents are strong and the Bay currents weak, then the trough will be carried over the Hima-

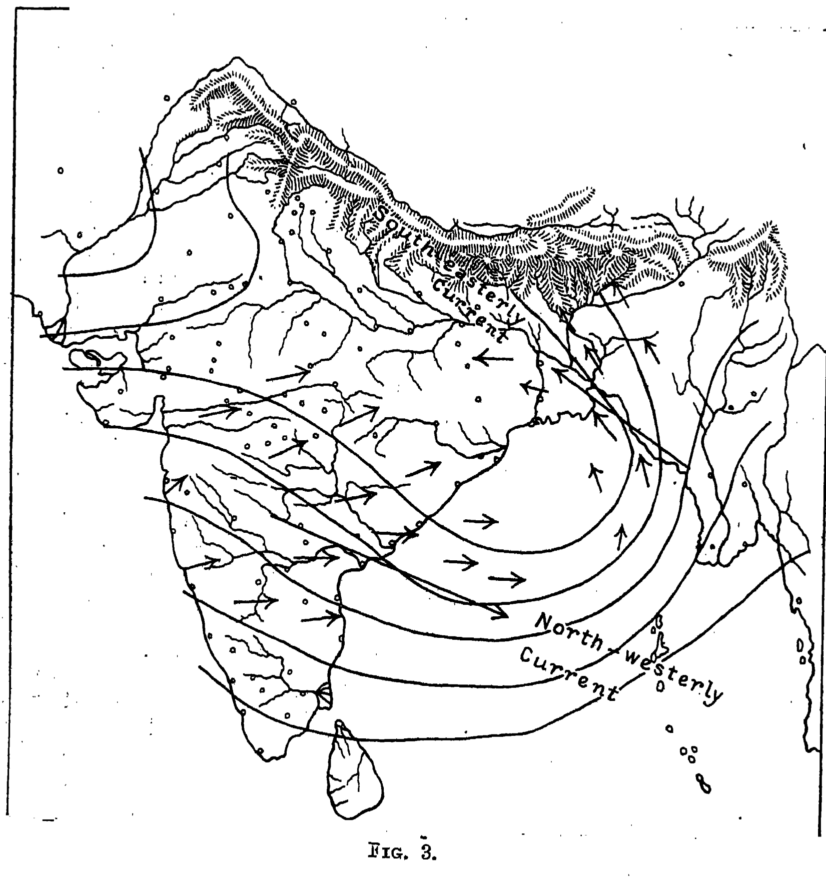

FIG. 3.

layan hills but if the strengths of the two currents are nearly equal, then the trough will extend from the Bay of Bengal right up to the north-west frontier. It is when the trough occupies such a position and comprises a considerable area of the north of the Bay of Bengal, that conditions become more or less uniform and when this happens, the sky is usually clear and temperature high, and consequently thermal convection of

moist air starts over this area. But for the initiation of the cyclonic circulation, it is not difficult to see that the isobar round the area of low pressure, if it is supposed to correspond to 0·5 km. winds, will readily indicate that a south-easterly current has a north-westerly current on its southern side over this part of the Sea. As has already been pointed out, two such opposing currents may perhaps engage each other and result in a cyclonic circulation. The thermal convection of moist air as well as earth's rotation will help in the process of the development and will in general serve to maintain it. This view of the initiation of the cyclonic circulation clearly explains why it is that the circulation always begins at one end of the trough of low pressure and not anywhere over this area. Over the greater part of the trough, except at the extremities, the two currents simply meet each other face to face giving rise to ascentional movement. Even at the extremity of the trough over the Bay of Bengal, although the condition of an easterly or south-easterly current having a westerly or north-westerly current on the southern side may be fulfilled and a circulatory motion may be initiated, yet no storm may be forming, unless there is a convection of warm moist air over this area to help in the process, and we often find the trough of low pressure extending over the Bay of Bengal with no generation of storms properly so called.

Counter-currents therefore can only initiate conditions that may give rise to circulatory motion in the air. For the maintenance of the circulation we must look to an altogether different source of energy. The next important point then is the consideration of the energy of the cyclones and in discussing this matter we cannot do better than begin with the remarks [1] made by Prof. J. von Hann in the recent discussion in *Nature* on this subject: "It is impossible to apply to these cyclones the theories which ascribe the energy of the rotating-wind system to the re-adjustment of equilibrium of warm and cold masses of air within that system, since in the cyclones of the tropical zone temperature and humidity are symmetrically distributed. In these cyclones warm and cold sectors do not exist. The Indian Meteorologists Henry Blanford, Sir John Eliot, F. Chambers, and W. T. Wilson have published papers on the cyclones of the Bay of Bengal and the Arabian Sea, giving a full explanation of their origin and development. These very important works no longer receive the attention they deserve. They also throw much light upon the source of energy in these cyclones. I endeavoured to make a rough calculation of the energy contained within one of the whirls (Backergunge Cyclone), taking into account the preceding pressure distribu-

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[1] *Nature*, March 3, 1921.

tion over the hurricane region, and the results were in good agreement with the observed wind forces. I should therefore like to direct attention to this work." [1]

In his article on the energy of cyclones in *Nature*, November 25, 1920, Sir Oliver Lodge points out an important source of energy for the maintenance and intensification of cyclones. He says: "Atmospheric pressure being a ton weight per square foot, the disappearance or collapse of a cubic foot of ordinary air would yield a foot-ton of work. The disappearance by complete condensation of the aqueous vapour in 760/12·7, say 60, cubic feet of atmosphere would yield the same amount. If then the temperature of saturated air fell from 18° to 12° C, by reason of condensation and rainfall so that the vapour pressure diminished from 15·36 to 10·46 mm. of mercury, one foot-ton would be generated in each 155 cubic feet of that region of the atmosphere. Incidentally the corresponding deposit would be 5 grams per cubic metre, a rainfall of ⅓ in. from a vertical mile of air. Assuming that the above fall of temperature in the central region of a travelling cyclone is not excessive, the energy available in each cubic mile of it would be nearly a thousand million foot-tons." As has been pointed out by W. H. Dines (*Nature*, Dec. 23, 1920), Sir Oliver seems to have overlooked the result of the heat set free by the condensation of the vapour and in fact if the heat energy due to the latent heat of vapour all took the form of kinetic energy in the atmosphere, quite a trifling rainfall would suffice to produce over the same area the most violent cyclone ever recorded.

Sir N. Shaw in his recent article [2] on the births and deaths of cyclones says: "Considering, then, cyclones to be dynamical systems of revolving air formed in a flowing current, it seems hardly possible to find any source except convection, reinforced by the latent heat of condensation, for the vast amount of energy which they develop. The velocities are so much greater than anything which occurs outside their spheres of action that the attempt to derive their energy from pre-existing air currents is not encouraging," and again: [3] "The selection by tropical cyclones of the localities of hottest sea water for their place of birth or nurture is certainly suggestive of convection from the surface as their cause; and the recent investigation of the upper air enables us to say that conditions have been ascertained which, if brought into juxtaposition, could produce certain results of the proper order of magnitude for tropical cyclones. For example, from the soundings of air at Batavia on the island of Java, we obtain an average or

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[1] Lehrbuch der Meteorologie, 1901 edition, p. 579, footnote.
[2] Geophysical Memoir, No. 19, 1922, p. 216.
[3] Geophysical Memoir, No. 19, 1922, p. 219.

normal representation of the lapse of temperature with height in the equatorial region, and we know also from Neuhoff's diagram and equation the effect upon temperature of adiabatic changes of pressure in the case of air saturated with water vapour at, for example, 300 A (about 80° F). We can set out these side by side, and we see at once that air saturated with water vapour at 300 A would be in unstable equilibrium. If it began to rise it would not find itself at the same temperature with its surroundings, and therefore not permanently in equilibrium, until the level of 15 kilometres had been reached, and only then if we suppose it to be loaded with condensed water as drops. After they had fallen out, further height would be required to bring the density of the rising air to that of its environment. There is nothing to excite surprise in this result, because we know from the results for temperature for equatorial regions that convection does go on there up to a level of 17 kilometres before the stratosphere is reached."

Now that it has been generally agreed that in the troposphere the core of a permanent extratropical cyclone is cold relatively to its environment and the interior region of an anticyclone relatively warm, Sir N. Shaw would consider the process of convection [1] to be fundamentally different from the traditional view of the phenomenon. In the atmosphere convection may apparently proceed either by threads or bubbles. If we conceive the process of convection as the passage upwards of a succession of innumerable large bubbles until many cubic miles of air have been lifted, the air originally over the area will have been gradually removed; the external air will have converged towards an axis and the beginnings of revolving flow will have been set up by the dynamical consequences of the original thermal process. Continued further, the same process will continue to remove the internal portion of the revolving column until the rotation with the aid of the original vorticity of earth's rotation has become sufficiently developed to resist further convergence towards the axis, and we have reached at all levels the condition of a simple vortex with a ring of maximum velocity. So far we have a warm core with an environment the temperature of which, except at the very bottom, is governed by the dynamical cooling due to the convergence towards the axis. But there will come a time when the supply of hot moist air at the surface is exhausted and then the passage of the air through the column by ascent from the bottom must cease. When that stage has been reached we shall have obtained a dynamical system consisting of a vortex with a ring of maximum velocity of finite diameter and its

[1] Geophysical Memoir, No. 19, pp. 221-222 (1922).

interior protected from further invasion, except at the bottom, by the velocity of rotation, so that it can only be affected by the creeping of air or other material into the interior along the bottom. The temperature distribution will be that produced by the convergence of the environment towards the axis; the whole effect of the convection, originally due to the heated and saturated surface air, will have been to cause the removal of the air from along the axis, which Lord Rayleigh's exposition [1] requires for the formation of a vortex of revolving fluid. Thus the high temperature of the interior is merely a temporary incident in the formation of a cyclonic vortex. By the time the vortex is developed as a dynamical system, the core is cold; there is no longer any convection in it; it becomes a comparatively small area, protected from the ordinary vicissi tudes of weather by the enormous momentum of a vortex with a high rate of spin, represented by the very violent winds of the ring, but extending in less violent form over a vast area.

The process of convection by the passage upwards of a succession of innumerable bubbles contemplated by Sir N. Shaw although very ingenious will necessarily imply certain physical conditions associated with their formation. Till these conditions have been investigated and it has been definitely proved that tropical cyclones have also cold cores like the extra-tropical, doubts will naturally be entertained about the existence of a process of this kind on a large scale. Even if the process of convection be initiated by the formation of bubbles and their passage upwards, it is not clear whether when the bubbles become sufficiently numerous, the process will not for all practical purposes become identical with convection by threads. The above explanation of a cold core will perhaps still remain true. But when the vortex has developed into a dynamical system and the convection has ceased which will necessarily imply cessation of fresh supply of energy, it will still require investigation whether the momentum of the vortex is really enough to maintain it for days and whether when such a stage is reached it can be made to conform with the observed fact, that even a fully developed cyclonic system sometimes deepens during the course of its travel, by simply considering that the deepening or weakening of a cyclonic system is entirely due to a contraction or expansion of the ring of maximum velocity. At any rate the factors which contribute to such contraction or expansion of the ring when convection has ceased will have to be enquired into.

An important question which arises in this connection is whether the whirl first starts in the upper air and is then transmitted to the ground surface or vice versa. Sir Napier Shaw

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1 Proc. Roy. Soc., pp. 148-154, Vol. XCIII (1917).

remarks[1]: "We have no satisfactory information as to the level at which the development of a column of rotating fluid begins nor how far up it extends. If it originates spontaneously with convection the rotation must presumably, from the experimental analogy,[2] begin in the layer from which the ascending air is drawn, and whether it subsequently extends upwards we cannot say, but we may show that the rotating motion will always extend downwards to the earth's surface if the convection persist long enough.

"The rotation will develop a circular distribution of pressure which on the principle of transmission of fluid pressure will be transmitted to all the layers beneath. Those layers at the first setting up of the circular isobars within them will not have the rotation which keeps the fluid from moving towards the axis to fill up the low pressure; consequently the air will move inwards towards the core and the part immediately below the core of the whirl will pass upward into the core; the air moving inwards in the layer beneath will gradually develop rotation which will balance the distribution of pressure, and so the core will gradually be drawn out of the column beneath and rotation set up provided that the convection up above is strong enough to carry with it the air supplied from the core of the column beneath. Thus the sudden creation of a circular field of pressure due to the convection will set up a sort of trunk of "suction" along the core which will extend further downwards as the rotation gradually develops and ultimately reaches the ground. If the original instability is very marked it seems possible that the suction at the ground, when the core reaches it, might be very strong and the inrush and the uprush of air near it very powerful. This process on a large scale might account for the carrying up of dust, sand, small fish and other objects into the core and so upwards into the air."

An illustration of this process may be found during the progress of a storm over mountain barriers. Cyclones from the Bay of Bengal sometimes move westwards over the Peninsula, cross the Western Ghats and then travel over the Arabian Sea. It is unlikely that the cyclonic system will be bodily raised up by the barriers if by raising up we understand that the whole air column will be raised up because this lifting up will be inconsistent with the density distribution in the atmosphere. The process can of course be driven upwards. But

1 Manual of Meteorology, Part IV, p. 144.

2 Notes on the Dynamics of Cyclones and Anticyclones, by John Aitken, F.R.S., Parts I and II, *Trans Roy. Soc Edin.*, Vol. XI, p. 131, 1901; Part III, *Proc. Roy. Soc. Edin.*, Vol. XXXVI, p. 174, 1916. 'Revolving fluid in the atmosphere,' *Proc. Roy. Soc.*, Vol. XCIV, p. 250, 1918.

what seems to be more probable is that the lower part of the system is cut off by the barrier. In other words, friction with the rugged ground surface of the Peninsula and of the mountains set up turbulence which almost destroy the lower part of the cyclonic system. Consequently the system becomes very weak and makes a very poor impression on the synoptic charts during its travel over the Peninsula. By the time the system has crossed the Western Ghats, the cyclonic circulation exists only in the upper air and it takes one or two days to transmit the circulation to the sea surface. In consequence for a day or two practically no trace or a very feeble trace of the cyclonic system is to be found in the synoptic charts. But once the circulation has reached the ground surface, convection of warm moist air will start along the core and the system will gain energy. It will gradually develop and for the rest of its course, it will probably travel as a dangerous cyclone. (See weather charts for Nov. 4th to 15th, 1886; Nov. 5th to 11th, 1898; Oct. 15th to 24th, 1916; Nov. 1st to 8th, 1919.)

If the cyclone has not been well-developed the turbulence set up during its travel across the Peninsula may be enough to destroy it completely. A large percentage of cyclones will therefore never get across the Western Ghats. As another example, it may be mentioned that the western disturbances which come from the Atlantic Ocean or the Mediterranean Sea and invade India have to cross mountain ranges varying in height from 7000 to 14000ft. and by the time they reach India, the disturbances only exist in the upper-air.

Sir Napier Shaw[1] in considering the height of cyclones lends support to this view: "The height of a range of mountains is sometimes assigned as the limit of the height of a cyclonic storm because it was found to have died when it passed over the range. The conclusion seems scarcely justified. No doubt a mountain range, 2 kilometres high, for example, would cut off the bottom 2 kilometres of the cyclone, and, unless it could rapidly extend itself to the surface on the other side of the range, it would fill up. In any case it would have to take a great deal of air from the other side into its interior in order to remove a core from the lowest 2 kilometres. It has the machinery for beginning the process, namely, a suitable distribution of pressure which it can superpose upon the lower strata; but whether the air which it thus takes into its interior can be thrown out at the top, and used to scour the column and maintain the cyclone, depends upon its temperature and humidity. If the travelling revolving mass happens upon a suitable sample of surface air, well and good; but if not,

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1 "The Birth and Death of Cyclones," Geophysical Memoir, No. 19, 1922, p. 224.

it perishes by being filled up. Hence the annihilation of a cyclone by a range of mountains is not a real index of its height, and the fact that cyclonic depressions sometimes cross mountain ranges and re-establish themselves on the other side, though many perish, suggest that the dynamical conditions to extend to great heights."

THE VELOCITY OF TRAVEL AND THE TRACKS OF THE CYCLONES OF THE INDIAN SEAS.

The translation of a cyclone is commonly attributed to the general motion of the air over the region in which it is found. This conclusion may appear to be quite logical, for, if the velocity of translation were greater than the general velocity of winds around the cyclone, it would imply that the depression moved at such a rate that no part of the surrounding air could keep pace with it. If the velocity was less it would mean a congestion in the rear of the cyclone which cannot be contemplated. Although this may perhaps be the general cause which controls the motion of a cyclone, it is essential, in order to understand fully the apparent complexity of the tracks of cyclones and also the velocity with which they travel, to refer to synoptic charts of pressure, temperature, surface winds, free air winds, and clouds over wide areas. Without reference to synoptic charts, rather abrupt conclusions may often be made regarding the laws of motion of cyclones, from an examination of their tracks for a considerable number of years, for any given month, plotted on a single chart, which may not have any foundation in fact. For instance, an examination of the storm tracks for the month of April (see Meteorological Atlas of the Indian Seas) may lead one to conclude that storms, formed during this month in the Bay of Bengal as well as in the Arabian Sea, have a peculiar tendency to move parallel to the coast. The tracks for the month of May may even lend support to this view. An examination of the synoptic charts for any storm formed during April or May will show, however, that these storms are generally formed during a temporary advance of the monsoon winds and that in the Arabian Sea as well as in the Bay of Bengal, these monsoon winds generally blow northwards or northeastwards and that these prevailing wind directions for the time being probably regulate the course of the storms making them appear to follow tracks parallel to the coast. During the monsoon months the general drift of winds will tend to move a storm formed at the head of the Bay along the trough of low pressure parallel to the Himalayan range in a westerly or northwesterly direction. But if the trough itself shifts its position, say northwards, during the movements of the storm, the course of the storm may be altered accordingly.

If the cyclones of the Indian Seas be considered to be dynamical systems of revolving air formed in a flowing current, a velocity of travel of ten or twelve miles per hour for these cyclones will not be inappropriate. It is also not difficult to understand why different cyclones should travel with different velocities according to the strength of the flowing current in which they are embedded at the time. It is usually noticed that a shallow depression travels with a much greater velocity than a deep one. In connection with his disc theory of travelling cyclones Sir N. Shaw [1] says: "There are two features of agreement which are very striking, one is the existence in the real case of close isobars in the form of incomplete circular arcs which are required to complete the mapping of the revolving disc in the theoretical map. They will be recognized as *characteristic of small cyclones which travel rapidly*." I find it difficult to understand from the analogy why a shallow depression should move rapidly although such depression will be recognized to have isobars in the form of incomplete circular arcs. According to his disc theory, the tornado centre and the kinematic centre are separated from each other by a distance V/ζ, where V is the velocity of travel and ζ, the angular velocity of rotation of the cyclone. For a shallow depression ζ is comparatively small, and as the isobars deviate considerably from circular shapes, the distance between the tornado centre and the kinematic centre is fairly large and consequently the velocity of travel must be comparatively greater. Probably Sir N. Shaw had some such arguments in his mind although I am not at all clear about this matter. We may perhaps consider this point in an altogether different light. We may regard roughly the pressure field at the ground surface (or at any rate at 0·5 km. level) due to a cyclone to be the combination of two fields, the first consisting of a series of straight isobars and the second a system of circular isobars representing the cyclonic circulation. The normal wind velocity in the first field of straight isobars will in general determine the velocity of travel of the cyclone. It is a matter of common experience that the more dangerous cyclones usually form in an area of practically uniform pressure, that is to say, in a field in which the isobars are wide apart and consequently the gradient is very small. In other words, a close system of circular isobars may be easily embedded in a field having straight isobars wide apart. But the formation of a shallow depression will not usually require such a wide field of uniform pressure and may be embedded on a comparatively close system of straight isobars and will consequently have a proportionately larger velocity of travel.

[1] Sir N. Shaw, Manual of Meteorology, Part IV. p. 127

It is not easy however to give a general discussion of the direction and the velocity of travel of the storms that form during the transition periods. The tracks do not seem to obey any general law and individual cases must be separately considered. But obviously if the barometer shows greater fall in any particular direction than in others, the system of isobars will have to adjust itself to conform to this fall and the storms

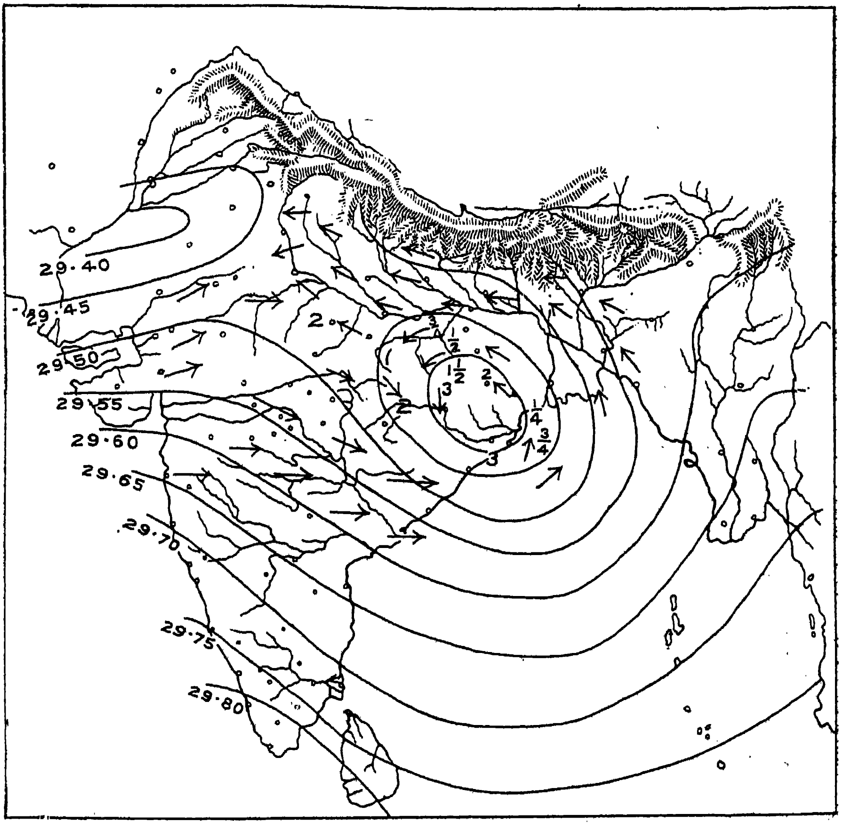

FIG. 4.

will consequently move in that direction. This is an important indication of which every advantage is taken in practical forecasting. For the purpose of forecasting the movement of a storm, various factors, which accompany the process of movement, are taken into account; for example, the falling barometer in front, the heavy cloud moving ahead of the storm, increase of humidity and the peculiar run of isobars very often give

a correct indication of the direction of movement of a storm.[1]

But the fact, that storms may originate in any part of the Bay or the Arabian Sea (except during the monsoon months) and that their tracks are as varied as their places of formation, has led others to disbelieve that the movement of storms can be satisfactorily accounted for by the theory of flowing currents. It is not necessary in order to explain the movement of tropical cyclones to consider the cyclonic system and the flowing current, if any, as two distinct systems and an explanation of the movement may be obtained from the mechanism of the cyclonic system itself. The centrifugal force of a tropical cyclone, especially at the outer margin, is not strong enough to keep the monsoon winds feeding into it revolving in a circular path with the result that these winds after making a small turn deviate from the circular path and carry the cloud ahead of the storm. The precipitation and the consequent latent heat set free in front of the storm reduce the pressure there necessitating a readjustment and a shifting of the isobars. This in general accounts for the movement of the storm. It is of course implied that it is not the general drift of winds that makes the storm move but that the movement of the cyclone involved in its mechanism makes the outlying winds adjust themselves to the motion.

Dissolution of Tropical Cyclones.

In a remarkable paper[2] dealing with the life cycle of cyclones and the polar front theory of atmospheric circulation, J. Bjerknes and H. Solberg have given the following picturesque description of the life history of the extra-tropical cyclones: " During the eastward motion, the amplitude (in a horizontal N-S direction) of the warm wave increases. The cold air curves round the northern end of the warm tongue and arrives as a north-westerly current behind the centre. This type corresponds to an *ideal cyclone.* Simultaneously with the further increase of amplitude the warm tongue narrows laterally, especially in the southern outskirts of the cyclone. Finally the cold air from the rear of the cyclone reaches the cold air from its front, and thereby cuts off the warm sector. In this phase when the cyclone has cut off its warm air supply, it is said to be *secluded.* The remaining part of the warm sector near the centre also disappears fairly soon, so that the cyclone on the ground only consists of cold air. For this type we have chosen the name *secluded* cyclones. At the

[1] For fuller discussion about this matter see Eliot's Handbook of Cyclonic Storms in the Bay of Bengal.

[2] Geofysiske Publikationer, Vol. III, No. 1, p. 4 (1922).

place where the warm sector disappeared, a boundary line still exists for some time between the cold air from the rear and front of the cyclone respectively. Finally, also this boundary vanishes, and the cyclone becomes a nearly symmetrical vortex of cold air. The large zones of continuous rain have then disappeared, and the precipitation falls only as showers. These conditions then persist until the cyclone dies."

Although the process of death of extra-tropical cyclones, herein described will not apply literally to a tropical cyclone, Sir N. Shaw points out[1] that the death of a tropical cyclone is quite in accord with Professor Bjerknes' explanation of the strangulation or starvation of cyclonic depressions by the grip of the polar front. A tropical cyclone regarded as a dynamical system carried along by the easterly drift, or in the prevailing westerlies, is protected by the inertia of its rotary motion from attacks from the outside except at the bottom. As it passes over the surface of land or sea it sweeps into its inner rings whatever it may find close to the surface, birds, butterflies and other living creatures are often included. But it cannot lift the included material throughout the whole length of its column. So long as the surface air, which is dragged into its interior in this way, is warm enough to cause local convection in the region to which it is carried, additional energy is conveyed to the dynamical system; but when a layer of cold air is attacked the convection only extends until the temperature is reduced sufficiently for the air to remain in dynamical equilibrium with its surroundings, and the addition of mass to the interior, instead of helping to scour the column, increases the pressure there. The ring of maximum vel[illegible] is, therefore, enlarged but its velocity is diminished. As process is continued, the central pressure continually incr and the ring of maximum velocity is widened and depre and the cyclone dies, although it may sometimes be a ling death.

Although the slow starvation of a cyclon[illegible] may be sufficient to cause its death, Sir N. Sha[illegible] nizes that there are other ways in which its e[illegible] brought to an end. But the example[2] he p[illegible] connection, namely, that the shearing of the with reference to its foot by difference of ve[illegible] levels in the air which carries it might bring its end will perhaps require further elucidation.

It will of course be admitted that if there [illegible] able gradient of wind upwards, positive or negativ[illegible]

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1 Geophysical Memoir, No. 19, pp. 223-224.
2 Loc. cit., p. 224 (1922).

must be a continual shearing of the cyclone and the shearing must either be continually countered by the cyclone, or it must die. But the question is whether there are occasions when a cyclone has to face such a strong vertical gradient of wind and if there are what vertical gradient a cyclone can stand and continue to live? With regard to the first point, from an examination of the symmetry of temperature and pressure, Sir N. Shaw remarks[1]: "If isobaric surfaces are also isothermal surfaces there is no change of wind velocity with height. In any case one would have to assume approximate uniformity of direction and speed for a thickness of several kilometers, in order to get a definite connected body of air in stable motion. Perhaps for the levels between four and eight kilometers there are enough occasions of little change of wind velocity between those levels to furnish convenient circumstances for the persistence of a sufficient number of cyclones or cyclonic depressions." The atmospheric conditions in the region surrounding a cyclonic depression are so different from normal weather, that it is perhaps quite incorrect to assume that the vertical gradient of wind, which a cyclone has to encounter, is roughly of the same order as the gradient derived from the observations of the motion of pilot balloons under normal weather. As pointed out by Sir N. Shaw, it is also a matter for careful consideration what is actually presented to us by the motion of a pilot balloon in a cyclonic depression. The irregularities due to local turbulence or the changes incidental to an inclined axis will appear in the results with as much weight as the cyclonic circulation. Perhaps the altered conditions of the atmosphere in which a fully developed cyclone finds itself do not permit of too much change of wind velocity with height and then all our conjectures regarding the supposed effect of a vertical gradient of wind on a cyclonic system will appear futile.

If a cyclone is to be considered a stable dynamical system consisting of a vortex with a ring of maximum velocity, as Sir N. Shaw considers it to be, and 'protected from the ordinary vicissitudes of weather by the *enormous momentum of a vortex* with a high rate of spin'[2] then as a vortex will ordinarily, except perhaps for the fact that the air is not a perfect fluid, form a closed system or end on boundaries, we shall have to assume that in a cyclone the dynamical conditions extend from the ground surface to considerable heights. Perhaps also the entire length of the vortex and not simply the length, where the sustaining energy is supplied, is effective in offering resistance to extraneous forces, because the energy, wherever it is supplied, will be distributed over the entire length and it is

[1] Geophysical Memoir, No. 19, p. 216 (1922).
[2] Loc. cit., p. 222, lines 43 to 46.

the momentum of the system which will offer resistance. The high degree of permanence of the type of motion is also suggestive that its enormous momentum does offer considerable resistance to all forces of destruction. A small vertical gradient of wind, if there is such a gradient at all, will therefore probably not shear a cyclone out of existence. It will perhaps deform the cyclonic system or make its axis inclined to the vertical; but if the gradient is considerable and of long duration and if the struggle to maintain its circulation and to remain reasonably erect proves too much for the cyclone, it will eventually expire.

The possibility of the axis of a cyclone being inclined to the vertical has long been surmised and Sir N. Shaw himself has advanced arguments[1] attempting to give definiteness to the meaning of this idea. It should however be remarked here that the axis of a cyclone being inclined to the vertical will have definite meaning only if the whirl is supposed to extend to great heights. But if the height is small, say only three or four kilometers, extending only a little beyond the levels where the sustaining energy is supplied, as some meteorologists[2] including Eliot and Dallas have supposed it to be, then as this height is small compared to the diameter of the core, the conception of an inclined axis for cyclones will be quite meaningless.

An important consideration to which we have in several places given expression in this essay will perhaps bear repetition here. It is the friction against land and sea introducing turbulence which will spread upwards, disturb and ultimately destroy the cyclonic system. If the cyclone has to travel over a vast tract of mountainous country, the turbulence set up will be considerable and will bring about a rapid destruction of the cyclone, especially if the air that feed the cyclone be dry.

CONCLUSION.

We must admit that considerable progress has been made in the development of the theory of cyclones but it will also appear from the foregoing pages that much remains still to be done and progress would be difficult and slow unless efficient arrangement be made for collection of accurate data, especially those of the upper-air.

The geographical position of India as well as its configuration and the predominating monsoon currents have all combined to make India a particularly suitable country for the collection of such data. Her coast stations and the island

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1 Manual of Meteorology, part IV, p. 145.

2 "Hurricanes and Tropical Revolving Storms," by Mrs. E. V. Newnham, Geophysical Memoir, No. 19, p. 232 (1922).

stations occupy unique positions in these respects. Nor can Indians afford to ignore the study of tropical cyclones. Their agriculture depends on an equitable distribution of rainfall over the country and much of the deficiency of this distribution, caused by the failure of the monsoon rains over certain parts of the country, are supplied by the rainfall caused by storms moving inland from the Bay of Bengal or the Arabian Sea.

While therefore a timely forecast of an approaching storm will enable cultivators to take the fullest advantage of the resulting precipitation, a timely warning regarding the probable tracks of dangerous hurricanes will save lives and properties, particularly in East Bengal abounding in river routes with country crafts as the chief modes of conveyance. No one will deny the importance to sailors of frequent broadcasting, from the radio-stations on the Indian coast, of messages giving the accurate position and the path of dangerous storms formed in the Bay of Bengal or the Arabian Sea; but those, who are responsible for this work, know very well how difficult is their task, how difficult it is to determine accurately the position of the storm-centre and the path it is going to take, from the available data. The Americans understand the importance of intensive study of weather and in the United States there are more than two hundred first-class observatories distributed over the country. In India we have hardly four first-class observatories and for want of funds, the activities of some of these had to be curbed in certain directions and at present only two of these four can afford the expense of sending out a balloon every day for the measurement of strengths and directions of upper winds. Let us anxiously look forward to the day when our countrymen will bestir themselves to develop the agricultural resources of the country and an increased prosperity of the country will make an organization like that of the American Weather Bureau possible in this country.

ssued April, 11*th* 1924.

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TWENTIETH INDIAN SCIENCE CONGRESS.

PATNA, 1933.

Presidential Address.

(Section of Mathematics and Physics.)

RECENT DEVELOPMENTS IN SPECTROSCOPY.

BY DR. A. L. NARAYAN, M.A., D.SC., F.I.P.

Section of Mathematics and Physics.

President :—Dr. A. L. Narayan, M.A., D.Sc., F.I.P.

Presidential Address.

Recent Developments in Spectroscopy.

Ladies and Gentlemen,

Before I take the Chair, I wish to express my sincere thanks to you and the Council of the Congress for the honour you have done me in electing me President for the Mathematics and Physics section of the Science Congress this year.

I take it that it was in recognition of a few contributions I have been able to make during the past few years. I may at once say that it would not have been possible for me to accomplish what little I have achieved if I had not the assistance of a few enthusiastic research workers, prominent among them being K. R. Rao, I. R. Rao, and A. S. Rao. Year after year the general convention seems to be that the President should deal in his address with some subjects in which he is interested and should give a generalised statement of his own researches. Just two years ago, Prof. Venkatesachar occupied the Chair and delivered one of the most interesting presidential addresses on Series Spectra and Hyperfine Structure of Spectral lines which is also my line of work.

I have, therefore, chosen 'Recent Developments in Spectroscopy' as the subject of my address. In the brief space at my disposal as it is not possible to treat the subject in a comprehensive manner, I propose to summarise my scattered ideas on principally recent developments, which have added much to our understanding of 'Matter and Radiation'. The last few years of the history of Spectroscopy furnish a striking illustration, first of the enormous output of work, and second, of the power of experimental and theoretical methods combined for predicting new phenomena.

Atomic Spectra and Vector Coupling.

The systematisation of spectra, due to Hund, starts chiefly from the work of Russel and Saunders on the spectra of the alkaline earths. Without doubt the greatest progress in the interpretation of complex spectra is based on the suggestions of Russel and Saunders; of Pauli and Heisenberg.[1] The great success of these new ideas is that they not only predict the optical terms of the spectra of a shell but are also able to show the necessity for the existence of shells and thus leads to a

complete theory of the Periodic system. Discovering a series of the so-called pp' groups, Russel and Saunders arrived at the conclusion that, when we consider the characteristic emission by an atom, we should take the effect not only of the one labelled, 'series electron', but that of all the outer electrons. It is not the orbital moment of only a single electron that should be quantised but the quantised resultant sum of the orbital momenta of all the individual electrons should be considered. This type of coupling of the individual '*ls*' of all the electrons is usually known as 'Russel-Saunders' or the normal type of coupling and is represented thus,

$$(s_1 s_2 \ldots)\,(l_1 l_2 \ldots) = (sl) = j.$$

This implies that the interaction energy of the spin moment 's_1' of one electron and *its own* orbital moment 'l_1' is much less than the interaction energy between the spin momenta $s_1 s_2$ of different electrons. In a two-electron system, it is as if the influence of the second electron on the first is equivalent to that of a strong magnetic field. The existence of such strong interaction energy between the spin momenta, strange though it seems to be from the ordinary viewpoint of the vectorial model of the atom, is, in reality, only a manifestation of the phenomenon of 'resonance' discovered by Heisenberg and Dirac.

With the adoption of this idea, the vectorial method of treatment has proved indeed to be most fruitful in the interpretation of spectra. The spectra of the lighter elements and generally those which occupy the right sub-group of the periodic table, do exhibit this normal type of coupling. Interval and intensity rules, deduced on the basis of this scheme, have approximately been verified in some of these cases. It must not, however, be concluded that this simple scheme of Russel and Saunders is universally applicable. There have already been found numerous instances of spectra in which a definite departure is noticed. It is, unfortunately, such spectra in which these departures are most marked that are most difficult to tackle. Notable examples of these are the spectra of the heavier elements like Thallium, Lead, Bismuth. Thallium IV—a platinum-like spectrum having a configuration of ten '*d*' electrons—exhibits a typical breaking off from the normal scheme. A detailed study of such spectra and of the anomalies that they present, is a subject of far-reaching importance and demands the careful work of several investigators.

In contradistinction to this normal '*ls*' scheme which properly should be termed as one limiting type, there is a second, the other extreme type of coupling which is designated as the (jj) coupling and represented as

$$(s_1 l_1)\,(s_2 l_2) \ldots = j_1 j_2 \ldots = j.$$

This occurs when the interaction energy between the spins

is not strong enough to break down the coupling between the spin and the orbital momenta of the individual electron and corresponds, therefore, to the effect of a weak field. Between these two extreme types, there may be various other intermediate possibilities, analogous to the case of fields of intermediate strength. But, whatever the type of coupling, we arrive at precisely the same number of different energy levels, characteristic of any atom, with the same values of j for these states.

It is extremely difficult to make definite conclusions about the nature of the coupling exhibited in any case, except where one of the two 'pure' cases—either the '*ls*' or the '*jj*'—holds good. There are generally three criteria available for such a study of the vector coupling in complex spectra; namely (1) the relative magnitude of the energy levels, (2) the intensities of the combination lines, (3) the behaviour of the lines in a magnetic field. Of these, at the present stage of development of experimental technique, a study by the two latter methods is beset with great difficulties. To any ambitious investigator a study of the intensities of spectral lines under different conditions offers certainly a very wide field for research. The deductions made from the third criterion of comparison of the relative energy levels are usually very reliable as they can be based on the definite experimental classification of the spectral lines; this criterion is often the first to indicate a breaking off from the normal coupling. It is found even in relatively very simple cases of spectra such as those of Ge I, As II, Se III, that there is an interpenetration of the different levels arising from a given electron configuration and that the intervals of even the deepest terms show marked abnormalities. It may not be out of place here to mention that during the last few years rapid progress has been made in the spectral classification of these elements by K. R. Rao and A. S. Rao and myself, and we have made an exhaustive analysis of these spectra in successive stages of ionisation and published numerous papers.[2]

A great deal of interest centres round the determination of the characteristic energy levels of various spectra. It was the discovery of these levels or so-called 'terms' in Hydrogen and other simple elements that paved the way to the fundamental ideas of Bohr; it was the analysis of the more complex spectra like those of Cr and Mn that led to a far-reaching extension of these ideas; it was the classification of the spectra of He and of the alkaline earths which contributed substantially towards a general systematisation of our knowledge of the mechanics of the atom; and it is not difficult to foresee that, one day, the success of the patient endeavours of some investigator in unravelling the extremely complicated structure of the spectra of the rare earths would be another landmark in the history of the development of this most fascinating field of spectroscopy.

I have confined myself in the above discussion to a method of treatment of spectra which depends essentially on a vectorial model of the atom. In spite of its inherent defects, and in spite of the more recent and exact wave mechanical treatment, the vectorial method is usually retained on account of its simplicity and the ease of visualisation.

VACUUM SPECTROSCOPY.

A great step forward in unravelling spectra was taken by Millikan and Bowen[3] when, in 1924, as a result of their work on series relations between spectra of stripped atoms, they made an important discovery that the so-called 'regular' and 'irregular' doublet laws of X-ray spectra are applicable also in the optical region, while different explanations have hitherto been given for them in the two fields. In the X-ray region the doublets are explained as due to different shapes of orbits involving differences in shielding and relativity correction, while in the optical region they are due to the differences in the orientation of series electron orbits with respect to the atomic residue. This discovery opened up a new and unexpected difficulty in our understanding the origin of the X-ray doublets, which then were believed, according to Sommerfeld, to arise from a relativistic change in the mass of the electron. The difficulty remained unsolved till, on the basis of Goudsmit's[4] spinning electron, Heisenberg and Jordan and later Darwin[5] obtained exactly the same formula as Sommerfeld did, on the assumption of the relativistic mass. The mechanism which gives rise to these doublets lies therefore in the magnetic interaction between the spin moment of the electron and its orbital motion; the doublets are no longer 'relativistic' but may properly be called 'magnetic' or 'spin' doublets. This assumption constitutes a fundamental advance in our understanding of the nature of the ultimate thing with which Physics deals, viz. the electron.

Apart from the theoretical importance, the discovery of Millikan and Bowen gave a fresh impetus to the study of the spectra of the elements in the very extreme ultra-violet. It placed in the hands of the practical spectroscopist a powerful weapon which he may wield with ease and confidence in attacking even the most complicated spectrum with great success. The discovery itself was due, indeed, mainly to the development of the technique of Vacuum Spectroscopy. In spite of years of work in experimental spectroscopy, the need for more work is still as great as ever; the characteristic spectra of many elements in the extreme ultra-violet beyond the quartz and Schumann regions are yet unexplored. It is gratifying to note that at Waltair, K. R. Rao has taken up a systematic study of the spectra of rare earths in this region. Vacuum spectroscopy

had made but just a beginning with the work of Millikan and Bowen. Its technique demands a great skill on the part of the investigator. The construction of the instrument itself for photographing this region of very short waves is extremely simple ; the essential difficulty arises in producing the necessary high vacuum in a chamber of capacity as high as a hundred thousand c.cms.

During the last three years, particularly through the work of Siegbahn and his collaborators at Upsala, an important modification has been made in the design of the spectrograph, which made it particularly suitable for photographing the regions of wavelength even smaller than 100A. The grating, instead of being mounted at nearly normal incidence as in the usual instrument, is mounted at nearly grazing incidence, thereby enormously increasing its reflecting power for extremely short waves.

Turning now to the sources that can be employed in vacuum spectroscopy, it may be remarked that the hot spark that is commonly used, is no doubt very rich in emission lines of atoms from which many or all of the outer electrons are completely knocked out. But, as a method of excitation of spectra, the discharge tube seems to afford a much wider range of ionisation. Figures I (*a*) and (*b*) are the photographs of the Giessler tube spectrum of As, recently photographed by Rao in the course of his analysis of the first spark spectrum. All the arc lines and lines of third and higher stages are completely suppressed and the first spark lines have all come out very prominently. I must here refer you in particular to the method of the hollow cathode discharge, in a rare gas atmosphere, designed and very widely used by Paschen and his collaborators. The method is particularly suitable for the investigation of the spectra of atoms in a low stage of ionisation. For the excitation of the spectrum in this source, occurs a so-called collision of the second kind between the rare gas atoms in a metastable or ionised state and the metallic atoms and is, therefore, limited by the energy of ionisation of the rare gas atom. This source gives beautifully sharp lines and lends itself specially for the investigation of the hyperfine structure of spectral lines.

Quite recently, in the course of their experiments on the spectrum of Arsenic by the hollow cathode discharge, K. R. Rao and T. S. Badami[6] found that the Lyman series of hydrogen came out with remarkable strength down to the fifteenth number, the important feature of the series being the curious intensity anomalies exhibited by the numbers (Fig. II). The suggestion is made by Rao that the phenomenon is caused by a transfer of energy by collisions of the second kind, between the ionised atoms of Arsenic in the metastable state and the atoms of Hydrogen. There is in this evidence of a new type of impact. If it should turn out that this type of collision

really occurs, it should have an important bearing on many discharge tube phenomena.

HYPERFINE STRUCTURE.

While working on the spectra of various elements, it has been found by several investigators from time to time that the lines attributed to electron spin are themselves composed of several components and that these fine structure separations are much smaller than the splitting due to the couplings between the extra nuclear electrons. This H.F.S. is explained by attributing to the nucleus of an atom a resultant spin momentum and therefore a magnetic moment, which is capable of interacting with the outer electrons. Fine structure observed in spectral lines might therefore be due to (*a*) the action of the nucleus of the atom, (*b*) its electron configuration, and (*c*) its isotopic features. During the past few years much has been written on the theoretical interpretation of these *hfs*. It does not therefore appear necessary to give an account of the theoretical details here. The theory predicts that the fine structure separations follow the interval rule accurately. Hargreaves[7] starting from the hypothesis of the nuclear spin, applied the methods of new quantum mechanics to the problem and derived intensity formulæ applicable in the general case. Hill,[8] Zeeman, Back, and Goudsmit[9] have similarly obtained intensity formulæ which are found to hold exactly in the case of several *hfs*. According to the Vector coupling scheme it will be expected that an unpaired '*s*' electron is most penetrating. At the time of its deepest penetration there occurs the strongest coupling between electron spin and nuclear spin which results in wide fine structure separations. Therefore in atomic systems where fine structure appears, wide fine structure separation occurs in terms associated with a deeply penetrating '*s*' electron. These separations are widest in the heavier elements of the periodic table.

If the *hfs* are to be attributed to the nucleus, then the spectra from a neutral atom or singly ionised or doubly ionised atom should all reveal the same spin moment for the nucleus. This has not yet been verified even in a few cases. Comparatively little work has so far been done on H.F.S. Even in the case of the few spectra that have been investigated, there seem to be considerable differences between the results of different investigators. The deviations in some cases are so large that it is difficult to interpret them as such. From the observational material available, it is difficult to say whether this divergence is due to the inadequacy of the theory or the extreme difficulty of experimentation. There is no doubt that for work in this field, greatest possible accuracy of observation and most careful judgment and discretion in the identification and measurement of satellites are necessary.

During the past two years, in the spectroscopic section of the Observatory at Kodaikanal, Rao and myself have made a systematic study of the H.F.S. of the arc lines of Thallium and Indium and of the spark lines of Arsenic and Bromine. Fine structure patterns are not generally completely resolved owing to the effect of the electric fields and pressures in broadening spectral lines. For studying the fine structure of the arc lines of Thallium and Indium we used a specially constructed vacuum arc of 2 per cent. amalgam of Mercury and Thallium and Mercury and Indium. The cathode was throughout kept cooled by surrounding with running water. The advantages of this type of source have been described by Venkatesachar in several papers. Owing to the extremely low partial pressure of Thallium or Indium vapour, the lines were found to be extremely sharp and without self-reversal. This vacuum arc was first constructed for precision wavelength measurements of the resonance lines of Thallium, with a view to identify the lines of this element in the solar spectrum. The evidence for the presence of Thallium wavelengths in the solar spectrum rests on two lines 5351 and 3775 ($6P-7S$) of solar intensities -3 and -2 respectively. In view of the fact that both these lines coincide with very faint solar lines and the line 5351 does not appear to be strengthened in the spot spectrum while generally all the arc lines are considerably enhanced, it would appear that the evidence for the identification of this element in the sun is very meagre. The fine structure was studied by using a quartz Lummer plate (8 mm. $\times$ 200 mm.) and a glass Lummer plate (4·8 $\times$ 135 mm.), and fused silica plate etalons of 2 and 2·5 mm. thickness. The fine structure of the arc lines of Thallium has previously been studied by Rewark and Chenault,[10] Back[11] and Wali Mohammad,[12] and more recently Mclennan and Crawford,[13] Schuler and Keyston,[14] Jackson, and by Rao and myself.[15] Schuler and Keyston and Rao and myself found an isotope displacement of about 0·05 cm^{-1} in the case of 5351 while Mclennan and Crawford discovered no trace of isotope shift.

Mclennan and Crawford and Schuler and Keyston found the line 3776 ($6P-7S$) to be a triplet and proposed a term scheme based on these measures. Though no isotope shift was found in this case, we pointed out that the line was found to have five components. At that time the component $-054A$ was not found on our photographs. In the plates subsequently obtained this component was clearly shown as will be seen from the microphotometric curves (Fig. III). From these fine structure measurements it was pointed out by us[16] that the complex structure could be explained by supposing that $^2P_{\frac{1}{2}}$ term like $^2P_{\frac{3}{2}}$ term shows an isotope shift of about ·05 cm^{-1}. The structure now given removes the anomaly noted by Schuler and Keyston in the isotope displacement of $^2P_{\frac{1}{2}}$ term. At the same time the structure observed by us still contains a com-

ponent $-117A$ which does not find a place in the scheme. This satellite has been observed previously only by Wali Mohammad. Recently Jackson[17] also made more careful observations on the structure of this line and revised his former results and proposed a level scheme which is substantially the same as ours. Only the satellite $-117A$ is not found in his measurements. The level scheme and line structure are shown in Fig. IV.

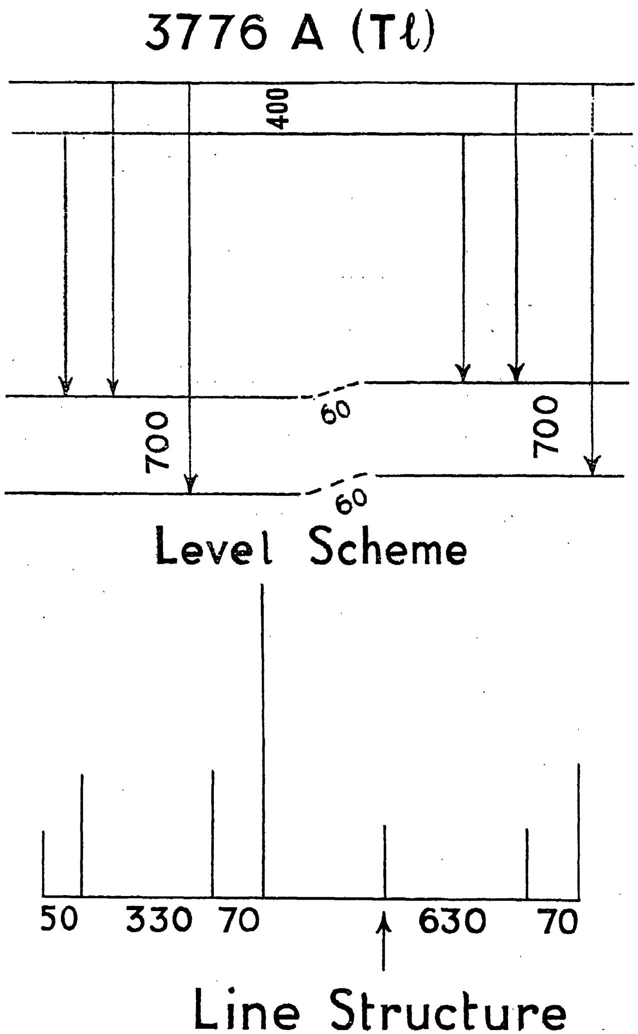


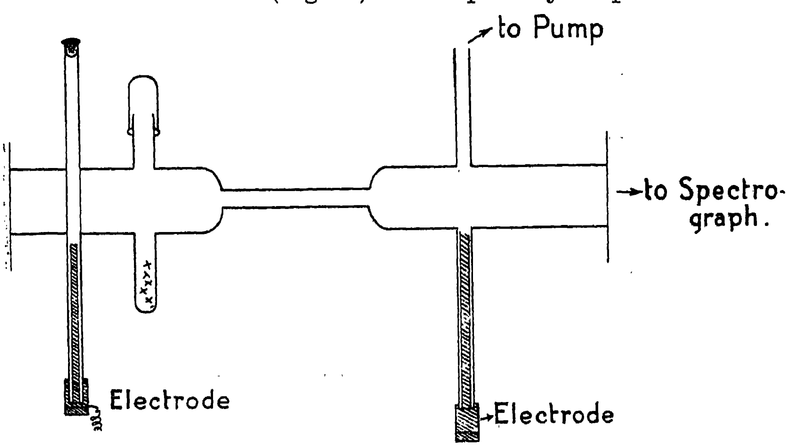
FIG. IV.

The fine structure measurements for 3776 are given in the following table and includes for the sake of comparison the data of Mclennan and Crawford, Schuler and Keyston, and Jackson :—

	in A	in cm^{-1}	Jackson	Mclennan and Crawford and Schuler and Keyston
3776	0·000	0·00	0·000	0·000
($6P—7S$)	—0·007	0·05	—0·007	....
	—0·054	0·38	—0·056	....
	—0·064	0·45	—0·065	—0·058
	—0·117	0·82	....	....
	—0·154	1·08	—0·157	
	—0·165	1·15	—0·165	—0·159

As we have pointed out recently in a note in 'Current Science' it is very remarkable that slight variations in the excitation result in marked changes in the relative intensities of the components. Pressure conditions seem to be very important in the excitation and therefore in the intensity relationships of the fine structure components. A similar fact was noticed by Schuler and Keyston [18] and Subbaraya and Iyengar [19] in the case of Mercury. It is nevertheless difficult to see how these slight variations in the conditions of excitation can influence the interaction between the nucleus and the electron shell.

While we were photographing the discharge tube spectrum of Arsenic for the gross multiplet analysis of As II it was found that certain prominent lines which should enter into the classification possessed a fine structure. A special investigation of the fine structure of the spark lines of Arsenic was therefore planned. In our experiments on the structure of the first spark lines of Arsenic, a Pyrex Geissler tube with capillary portion 10 cm. long and 1·5 mm. diameter with thick nickel electrodes was used (Fig. V). A quantity of pure Arsenic



DISCHARGE TUBE

is contained in the side vessel which was heated occasionally by passing a small current through the heating coil. In our experiments on Bromine, a quantity of pure copper bromide or silver bromide was contained in the side vessel. The observations were made end on. The pressure of the vapour and the discharge could be so adjusted that the lines of the first spark spectrum were emitted strongly and with fair sharpness. The fine structure in these two cases was examined in the region 6300A—4000A. Since these experiments were completed, Tolansky reported before the Royal Society[20] the results of his fine structure measurements on As II. It is to be noted that he based his studies on the unpublished data of K. R. Rao regarding the gross structure multiplet analysis. It is remarkable that the structures of some important lines differ markedly from our results. So far as I am aware the fine structure of the spark lines of As has not been studied by any other investigator. The *hfs* observed by us are given in the following table which includes the values of Tolansky for comparison :—

λ	Classification	Structure in $\Delta\nu$ (authors)	Tolansky
6171 ..	..	100, 0, 80, 115, 200?	118, 0, 76, 124, 201
6110 ..	$^1P_1$—$^3P_1$	309, 285, 200, 0	Single
6023 ..	..	190, 120, 0	198, 120, 0
5686 ..	..	80, 0, 80, 420	..
5657 ..	$^3P_2-{}^3P_1$	0, 100, 180	0, 117, 195, 225
5651 ..	$^3P_2-{}^3D_3$	0, 80, 130	0, 74, 112
5558 ..	$^3P_1-{}^3D_2$	100, 0, 40, 169	85, 0, 37, 112, 158
5498 ..	$^3P_0-{}^3D_1$	0, 195, 250 ?	Single
5331 ..	$^3P_2-{}^3P_2$	0, 90, 130	0, 88, 119
5231 ..	$^3P_1-{}^3P_0$	0, 190, 300	0, 197, 326
4985 ..	$^3P_1-{}^3P_1$	0, 185, 285	0, 194, 311
4888 ..	$^3P_0-{}^3P_1$	0, 210, 650	Single
4730 ..	$^3P_1-{}^3P_2$	0, 125, 200	0, 139, 230
4708 ..	$^1P_1-{}^1S_0$	0, 82, 150	Single
4371 ..	$^3D_3-{}^3D_2$	0, 100, 260, 485, 635	..
4336 ..	$^3D_2-{}^3D_1$	0, 170, 290	0, 160, 274, 321

The lines $\lambda\lambda$6110, 5498, 4888, and 4708 have been described by Tolansky as single, showing no trace of structure even with 2½ millions resolving power. Only, the two lines 6110 and 4708 showed distinct broadening towards the red. We photographed λ6110 using Eastman hypersensitive panchromatic plates. It will be seen from the photographic reproduction and the microphotometric trace that in addition to the strong satellite $\Delta\nu$, there are two faint satellites. [Fig. VI (*a*) and (*b*).]

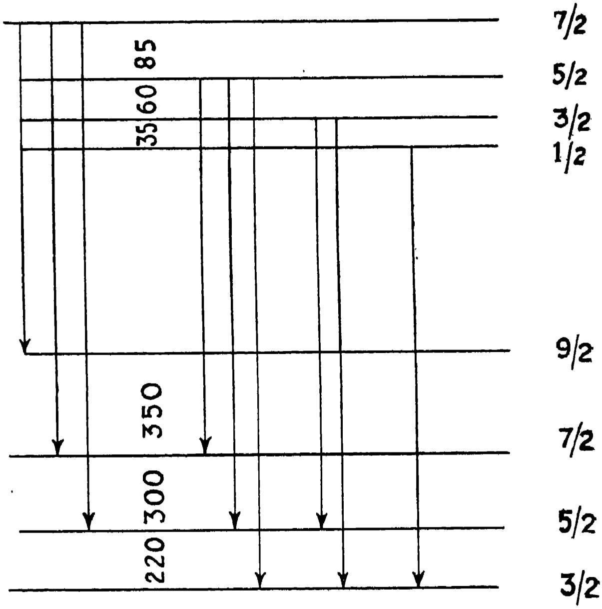
The line 5498 is found to have one satellite at $\Delta\nu=195$.

The wavelength of the other faint component has not been definitely fixed being very faint. (Fig. VII.)

$\lambda 4888$ shows a fairly strong satellite at $\Delta\nu=650$ while on some plates the second faint satellite at nearly $\Delta\nu=210$ is also shown. [Fig. VIII (*a*) and (*b*).]

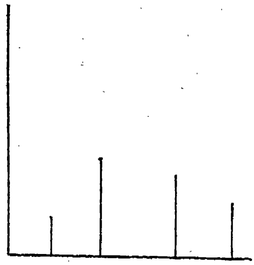
The line $\lambda 4708$ is clearly resolved in our plates and shows the fine structure given in the above table. All the components seem to be equally strong.

The lines 5686 and 4371 have not been analysed by Tolansky. When analysed by the quartz Lummer plate, the line 5686 showed hazy wings on both sides. But when analysed by the glass Lummer plate the strong satellite at $\Delta\nu=420$ is distinctly seen. The photographic reproductions and the density curves show this satellite. [Fig. IX (*a*) and (*b*).] We examined the line 4371$(4p'\,{}^3D_3-5p\,{}^3D_2)$ by two Lummer plates and a fused silica plate etalon and found it to be a group of at least four components. The satellite 100 cm^{-1} is not yet fixed with certainty. The level scheme and line structure are given in Fig. X (*a*), (*b*), and (*c*). It would appear that the line fits into the graph at a ratio of lower to upper interval factor of 100 : 26.



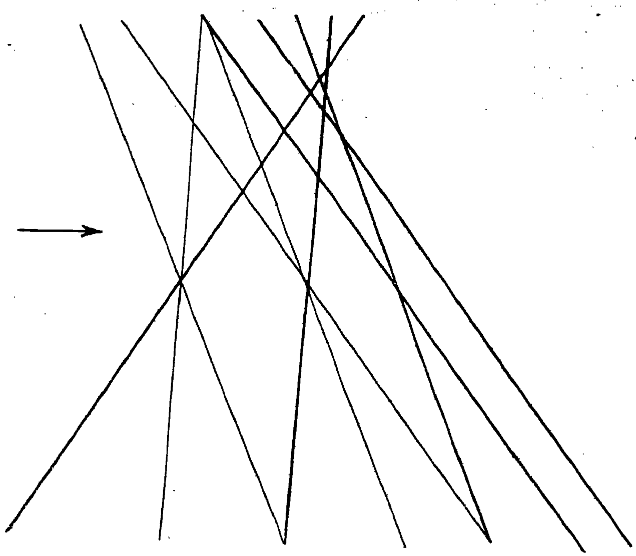
λ 4371.A.($^3D_3-{}^3D_2$) LEVEL SCHEME.

FIG. X (*a*).



λ 4371.A. ($^3D_3 - ^3D_2$) LINE STRUCTURE.

FIG. X (*b*).



λ 4371.A. ($^3D_3 - ^3D_2$) GRAPHICAL ANALYSIS.

FIG. X (*c*).

INTENSITIES OF SPECTRAL LINES.

The general theory of intensities of spectral lines is based on Bohr's correspondence principle of the probability of transitions from one stationary state of the atom to another. On the quantum theory of radiation specific relations exist between

the relative intensities of multiplet lines. In a series of papers published independently and practically concurrently, Sommerfeld, Ornstein, Russel, and Kronig[21] have generalised the 'Sum Rule' making it applicable to all types of multiplets. Measurements of relative intensities are therefore important from the aspect of the quantum and the intra-atomic theories.

By far the most important work in this field is described by Ornstein and his collaborators in a series of papers which contain much useful and interesting information about the technique. It is only in recent years, owing to the perfection of the experimental technique of photometry, that attempts to obtain quantitative intensity measurements have been made. In the majority of cases, the intensities of lines in multiplets are found to conform to the Sum Rule, though in complex spectra with wide multiplets the deviations are considerable. An important application of this theory of multiplet intensities is by Russel, Adams, and Moore,[22] to the calibration of Rowland's Scale of Intensities in the solar spectrum. The fundamental assumption underlying this work is that the intensities of lines in a multiplet are proportional to the corresponding intensities in laboratory emission spectra.

Owing to the difference in the conditions of excitation of the solar and the laboratory spectra, it is quite possible that this assumption is not quite justified. Attempts have recently been made by Woolley (Mt. Wilson Observatory) to obtain information on this point by measurement of the intensities of a few multiplets of Titanium and it is found that the divergence between the observed and theoretical values is very marked in many cases. In order to obtain more information on this point, I have recently carried out a series of experiments on a determination of the intensities of some important multiplets of Ni I in the solar and laboratory emission and absorption spectra. It will be remembered in this connection that Nickel contributes more than 600 lines in the solar spectrum and some of these are of the first order of intensity and lie in a region quite accessible to photography. Absorption spectrum was photographed in the laboratory by using an underwater spark between Nickel electrodes.

The solar and laboratory emission spectra were photographed in the 2nd order of the *13 feet* plane grating spectrograph (ruled surface of the grating being 6 inches). In all these cases one-half of the plate was exposed to the solar or laboratory spectrum and the other to a 6-volt 24-watt tungsten lamp used as a source of calibration. For varying the intensity during calibration slit widths of 0·4, 0·6, 0·8, and 1·0 mm. were used, the time of exposure being the same. All the usual precautions have been taken in developing and fixing the plates. These plates were later microphotometered on a Cambridge photoelectric microphotometer. Without going into all the

experimental details and results obtained, I shall briefly refer to a few interesting cases. Fig. XI shows a microphotometric curve of the underwater absorption spectrum of Ni in the region 3550 – 3300 A.U. Two typical multiplets occurring in this spectral region are given below and the intensities are given on a homogeneous scale :—

$a^3D - z^3F$

Intensity in

λ		Underwater spectrum	Sun	Emission
3515·067	..	24	26	22
3458·468	..	21	17	23
3433·580	..	15	17	17
3414·780	..	30	33	24
3361·571	..	9	6	13
		$a^3D - z^3P$*		
3524·54	..	43	53	39
3510·34	..	22	21	28
3492·97	..	34	26	33

* Only the diagonal lines are given here.

It will be seen from these and other multiplets thus far studied in the sun and the laboratory absorption, the stronger lines appear relatively much stronger, a fact which seems contrary to Woolley's conclusion that the weaker lines appear relatively stronger. A full account of these results will shortly be published in the Observatory Bulletin. It is important that further studies analogous to this should be conducted in other laboratories on gross and hyperfine multiplets.

A Few Important Applications.

Based upon the large amount of accumulated spectroscopic material and the multiplet behaviour of spectral lines, many lines in the solar and stellar spectra have been identified in recent years. An important outcome of this is that 57 elements have now been identified in the sun with certainty. As a result of the spectral theories and the ionisation theory of M. N. Saha, a comprehensive study of the physical character of the sun and stars has been possible. Saha derived the following equation from his ionisation theory :—

$$\log \frac{x^2}{1-x^2} P = \frac{-5050I}{T} + \frac{5}{2} \log T - 6{\cdot}5 - \log P_e,$$

where

x is the fractional number of ionised atoms in a given gas.
T is the absolute temperature.
I the ionisation potential.
P_e the electron pressure.

The equation shows that the percentage of ionisation increases with

(1) increase of temperature,
(2) decrease in pressure, and
(3) decrease in the ionisation potential.

The brilliant and detailed success of Saha's ionisation theory in predicting the physical characteristics of stellar spectra is well known to those engaged in the interpretation of these spectra. An important outcome of this theory is that we now conceive the chromosphere consists of a gas supported by radiation pressure acting on the atoms and that the sun must be surrounded by an atmosphere of free electrons.

Among the problems of special interest in Astrophysics at the present time are those concerned with the mechanics of the chromosphere and the prominences on the limb of the sun. It has been suggested by Milne and others that the energy which supplies motion to the prominences is furnished by selective radiation pressure and this radiation pressure is sufficient to explain all the phenomena observed in the prominences. During the past three years extensive observations (visual and photographic) have been made at Kodaikanal to determine the size and shape of the prominences on the limb of the sun in K light of Ca^+ and $H\alpha$ light of H. Recently T. Royds,[23] the Director of the Observatory, made an extensive study of these photographs and found that the prominences of different types are all of the same kind and are practically identical in both these radiations, as will be clearly seen from Fig. XII. The importance of these observational facts is that the selective radiation pressure alone cannot be supposed to support the prominences above the chromosphere.

Three of the outstanding problems awaiting solution for a long time in the field of spectroscopy are :—

(*a*) the origin of the famous green line 5577 in the spectrum of the auroral light and the spectrum of the moonless night sky ;

(*b*) the origin of certain unknown lines in the spectra of nebulæ ; and

(*c*) the origin of some of the most prominent lines in the corona.

The green line $\lambda 5577$ which is the most prominent in the spectrum of the auroral light and which is characteristic of the spectrum of the night sky has been the subject of extensive research. In 1925 Mclennan and Shrum put forward the view that auroral green line was identical with a sharply defined line which they observed in the spectrum of oxygen and that it is due to a transition between the low metastable energy states represented by $^1D_2$ and $^1S_0$, and they succeeded in photographing the entire auroral spectrum including the green line

as a part of the spectrum of the discharge in a vacuum tube containing mixtures of helium and air, helium and oxygen, argon and oxygen, and neon and oxygen.

On moonless nights when the sky was cloudless, Mclennan using a spectrograph and photographic method and Lord Raleigh using a photoelectric cell found that the intensity of the auroral green line radiation from the night sky, gradually increased to a maximum value about an hour after midnight and then fell off again with lapse of time to sunrise. Recently K. R. Ramanathan made a few observations on the general spectrum of the night sky in India. From the few preliminary observations now available, he believes that the variation of intensity in the green line radiation between sunset and sunrise is quite the other way about. If it should turn out that the observations of Ramanathan are real, it should have an important bearing on the structure of the upper atmosphere in our latitudes. Extensive observations are therefore necessary in this direction. They can be undertaken by people possessing even a moderate equipment. A simple camera can be made with a wide slit, a green filter, and a good lens. Records of the intensity of the green line radiation at intervals of an hour can be obtained during the course of a single night. There is no doubt that the atmospheric conditions in India are on the average exceptionally good and the number of clear nights is greater than in many other countries. It seems to me that the ozone content of the upper atmosphere may have an important bearing on these radiations. It would therefore be particularly interesting if observations could be made on the night sky radiation and if estimates of the ozone content in the upper atmosphere are also made side by side during the same period.

In the nebulæ are some prominent spectral lines which have never been observed in the laboratory. It was shown by Bowen[24] in 1927 that the eight strong nebular lines given in the following table—

Nebular Lines.

λ		Transition	Atomic System
7325	..	$^2D_{23} - ^2P_{12}$	O II
6584	..	$^3\bar{P}_2 - ^1D_2$	N II
6548	..	$^3\bar{P}_1 - ^1D_2$	N III
5007	..	$^3\bar{P}_2 - ^1D_2$	O III
4959	..	$^3\bar{P}_1 - ^1D_2$	O III
4363	..	$^1D - ^1S_0$	O III
3726	..	$^4\bar{S}_2 - ^2D_3$	O II
3729	..	$^4\bar{S}_2 - ^2D_2$	O II

originate in transitions from metastable states associated with atomic systems of O II, O III, and N II. It has been suggested that though under laboratory conditions the emission of radiation having these wavelengths seldom occurs, in a highly rarefied nebula, owing to the paucity of collisions of the second kind, these forbidden transitions can occur. Hopfield working in Paschen's laboratory obtained in the spectrum of oxygen under exceptionally heavy excitation the two nebular lines 6300 and 6364 A.U. These are the only nebular lines that have as yet been produced in the laboratory.

In the coronal spectrum are similarly found some of the most intense lines which have never been observed in the laboratory. The identification of most of these lines has not been possible so far. Hopfield believes that the red coronal line 6374·2 (In. 6) is identical with the unclassified oxygen-line 6374·29 and that this coincidence is strong evidence of the presence of oxygen in the solar corona. I hope that ere long it would be possible for some investigator not only to find a clue for the identification of these lines but to produce these spectral lines in the laboratory with a view to obtain information about the conditions under which these lines may be excited.

Molecular Spectra and Raman Effect.

After the advent of Bohr's theory, the spectroscopists engaged themselves exclusively to the study of atomic spectra for some time. But the extension of this theory to the explanation of molecular spectra by Schwarchild and others brought to light the importance of the latter to the understanding of molecular structure. The easy access to experiment of the visible and ultra-violet regions of the spectrum to which are confined the line spectra due to atoms, enabled a thorough investigation of the structure of the atom. In molecular spectra, though the electronic bands due to different molecules have been extensively studied, the rotation and vibration-rotation bands which respectively lie in the near and far infra-red regions have not been investigated at all, with the exception of those of a few gases like HCl, HBr, HI, H_2O, and CO.

Within the last decade, however, the investigations in the infra-red have received an impetus on account of their important bearing on theoretical physics. The diffraction grating in conjunction with the prism has enabled the workers in this field to attain a higher degree of dispersion, thus facilitating a resolution of the spectra formed in this region. Czerny's [25] work may be mentioned in this connection as an example of the important contribution of the study of molecular spectra to theoretical physics. His investigation of the pure rotation spectrum of HCl has convincingly proved the existence of half quanta in direct accord with the conclusions from Heisenberg's

Quantum Mechanics. We are still in the beginning of researches in the infra-red, and an extensive investigation in this region will give us much information regarding the dynamical state of molecules as the X-rays have given regarding their static condition.

The disabilities under which the physicist was working in the infra-red were removed by an entirely unexpected branch of physical research. The series of researches carried on at Calcutta by Raman and his collaborators on the classical scattering of light, which has thrown so much light on the structure of the molecules and their distribution in solids, liquids and gases, has resulted in the remarkable discovery of, what is nowadays known, as the Raman-effect.[26] It was theoretically forecasted by Smekal[27] in 1923, and by Kramers and Heisenberg[28] in 1925 in their classical paper on dispersion that a quantum of light incident on an electric oscillator cannot only be wholly absorbed or wholly scattered, but can also be partly absorbed resulting in a change of frequency of the other part which is scattered. This was experimentally achieved by Raman in 1928. The importance of this discovery to the understanding of molecular structure was realised by Raman himself. The improvement in the experimental technique of the Raman-effect made by R. W. Wood[29] has enabled many workers to investigate in this new field.

Briefly stated, the effect is simply this : when a light quantum of energy $h\nu$ is incident on a molecule in an energy state E_p, there is a certain probability of the molecule passing over to the energy state E_q with a change in the energy of the scattered quantum to $h\nu'$. The energy equation thus becomes

$$E_p + h\nu = E_q + h\nu'.$$

Thus

$$h\nu - h\nu' = E_q - E_p$$

or

$$\delta\nu = \nu - \nu' = \frac{E_q - E_p}{h}.$$

Here $\delta\nu$ can be put in the form

$$\delta\nu = \frac{E_e - E'_{e'}}{h} + \frac{E'_n - E_{n'}}{h} \frac{E_m - E'_{m'}}{h}$$

where E_e, E_n, E_m correspond to the initial, $E'_{e'}$, $E'_{n'}$, $E'_{m'}$ correspond to the final electronic, vibrational, and rotational energies respectively of the molecule

$$\delta\nu \gtreqless 0.$$

Thus the incident quantum may either lose or gain energy or may remain unchanged, entailing thereby a displacement of the spectral line corresponding to it either towards the red or the violet or no displacement at all corresponding to the

Rayleigh scattering. $\delta\nu$ represents the energy which a molecule is capable of absorbing or emitting and is therefore characteristic of it. This energy is well known to correspond (in general when $\delta\nu_e=0$) to the infra-red region of the sepctrum, and hence by a study of monochromatic light scattered by any molecule the change in frequency given by the shift in the spectral line representing the incident quantum of light, gives us the infra-red characteristic frequency of the molecule. Thus by Raman's discovery we have a new method of investigating the infra-red by work in the visible region of the spectrum with all its advantages.

Apart from its contribution to a knowledge of the characteristic infra-red frequencies of molecules, there have been, within the last four years after the discovery of the Raman-effect, applications of it to entirely unexpected fields of research. Rasetti,[30] working on the Raman-effect in gases, found lines which indicate rotational transitions $m \rightarrow m-2$, $m \rightarrow m$, $m \rightarrow m+2$ in agreement with the well-known selection rules deduced from the quantum-mechanical theory of dispersion. He obtained, corresponding to vibrational transitions in O_2, and N_2, lines with no rotational structure, which show the very high statistical weight of the transition $m \rightarrow m$ in changes involving vibrational energy.

The next important application of the Raman-effect is to verify the Boltzmann's law of distribution in the different states of energy of molecules in a substance at a particular temperature. Raman and Krishnan in their early work[31] found the possibility of verifying this law from a qualitative study of the intensity ratios of the Stokes's and anti-Stokes's Raman lines in carbontetra-chloride. The exact quantitative measurements were carried out by Ornstein and Rekveld.[32] By considerations analogous to those adopted by Einstein in his treatment of Planck's law, it is shown that the ratio of the intensities I_s and I_{as} of the Stokes's and anti-Stokes's lines in the Raman-effect is given by

$$\frac{I_s}{I_{as}}=\frac{\nu-\nu_i}{\nu+\nu_i}\,e^{h\nu_i/kT}$$

where ν is the frequency of the quantum of energy incident on a gas containing molecules, some of which being in a lower state of energy are in a position to absorb, and others in a higher state, in a position to emit, the amount of energy $h\nu_i$. The above ratio is deduced from an assumption of the Boltzmann law for the distribution of molecules in the different states of energy in a substance. The intensity ratio determined experimentally by Ornstein and Rekveld is found to agree very well with the value calculated from a knowledge of ν, ν_i, h, k, and T. Thus we have in this a remarkable method of establishing the validity of Boltzmann's law.

Kohlrausch and Dadieu[33] on the one hand and Daure[34] on the other have systematically investigated the Raman-frequencies in a large number of aromatic and aliphatic organic compounds from the chemical standpoint. They have beautifully established the regularities in the Raman-spectra of homologous compounds. The former found the binding forces between the atoms constituting these molecules. The differences in the aliphatic and aromatic binding of the C-H, C-C, C-O, C-N, etc. groups have been very well confirmed. In fact, Raman-effect has been studied more from the chemical than from the physical standpoint.

An entirely novel application of the Raman-effect has been made by Ramakrishna Rao[35] for the study of the nature of substances in a state of solution. By a measurement of the progressive changes in the intensity of the Raman lines corresponding to the undissociated HNO_3 molecules and the dissociated NO_3 ions in different concentration of nitric acid, he has occularly demonstrated the phenomenon of electrolytic dissociation. He has obtained by this method relative values for the percentage dissociation of HNO_3 in solutions of varying concentration, which for the first time are independent of assumptions regarding the mobility of ions. The importance of this method of determination of electrolytic dissociation lies in that the intensities, being proportional to the number of molecules or ions, give a direct estimate of the degree of dissociation, which is not possible by other methods. In addition, the method suggested by Ramakrishna Rao is applicable to high concentrations and promises to give a clue as to the nature of concentrated solutions which still remains a puzzle to the physical chemist. He[36] has also applied the Raman-effect to the study of the composition of water and of its variation with temperature and addition of electrolytes. The explanation of the changes which have been proposed by Ramakrishna Rao bear a certain resemblance to those which have been offered for the existence of anomalies in the specific heats of the solutions of electrolytes.

There are many more important applications of the Raman-effect, but the most recent is that by Raman and Bagavantam[37] involving a novel idea of the nature of light itself. By studying the polarisation of the Rayleigh and Raman lines in gases (hydrogen so far examined), they come to the conclusion that the intensity anomalies obtained by them cannot be explained on the classical ideas of the quantum. They suggest the existence of spin in it and thus explain their results. If further experimental work on other gases confirms this, we will have to attribute spin to the quantum also. If this result is established beyond doubt, the existence of spin as a universal phenomenon will be the inevitable conclusion.

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Tl 3776 A

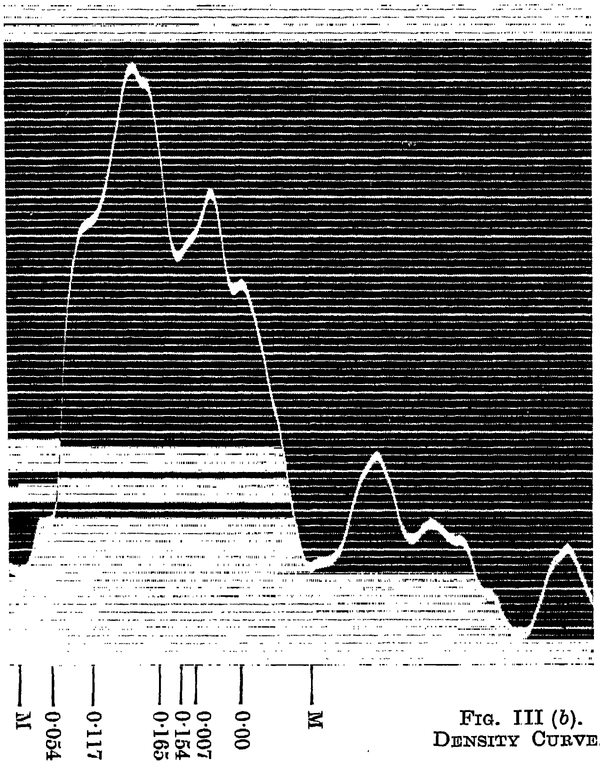


FIG. III (*b*).
DENSITY CURVE.

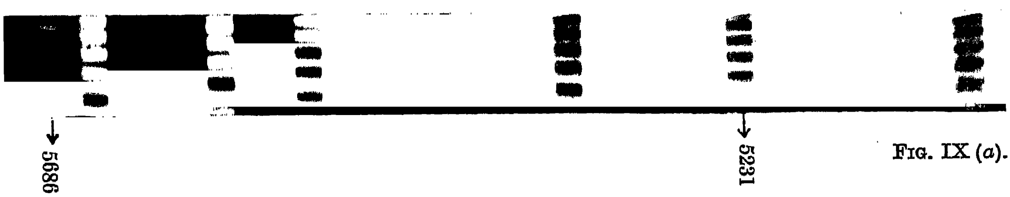


FIG. IX (*a*).

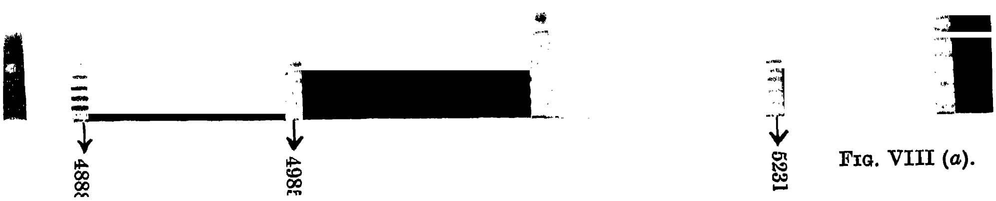
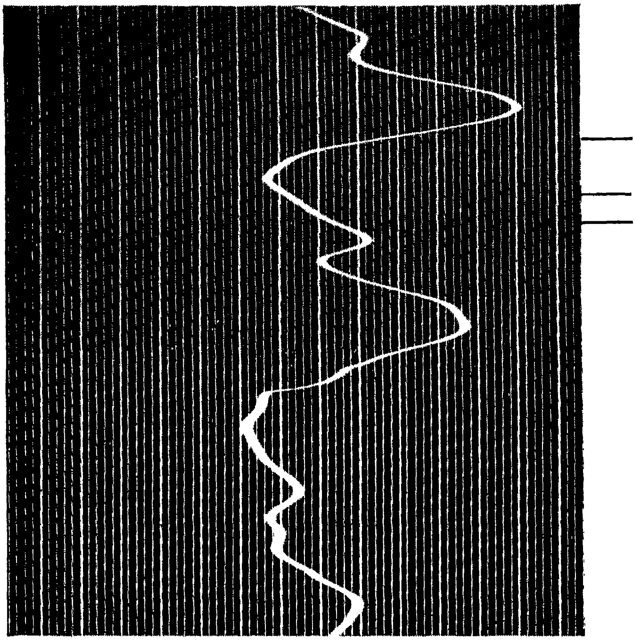
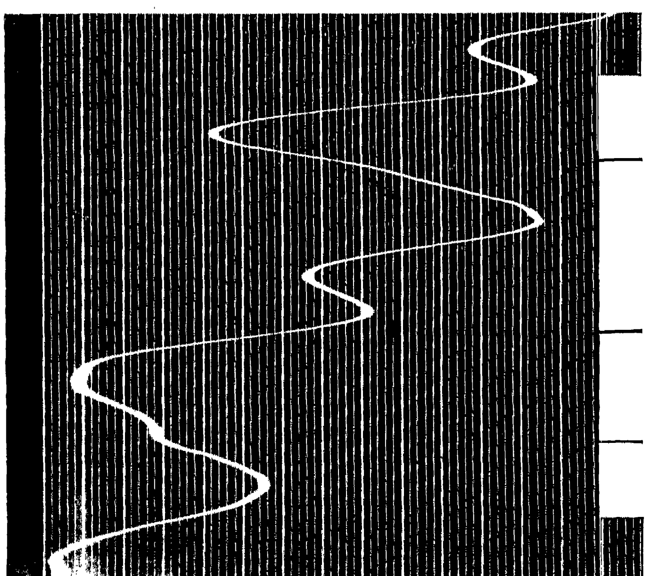


FIG. VIII (*a*).

FIG. VI (*b*).

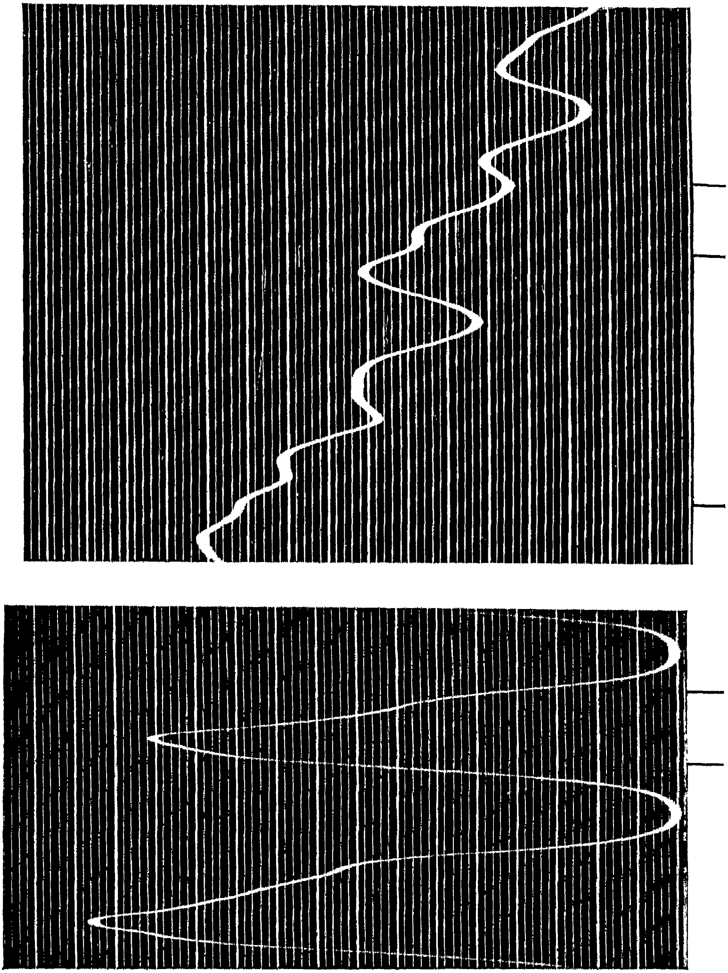


6110. A
Qz. L.P. (8 × 200 mm.).



6170. A
Qz. L.P. (8 × 200 mm.).

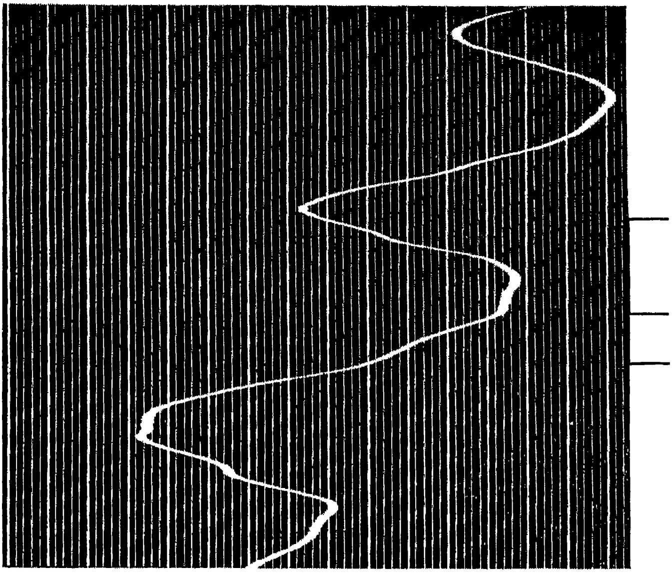
FIG. VII.



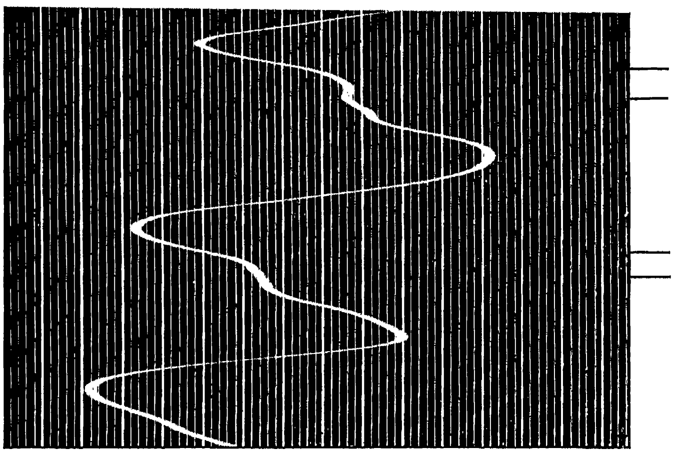
5231. A
Qz. L.P. (8 × 200 mm.).

5498. A
Qz. L.P. (8 × 200 mm.).

FIG. VIII (*b*).

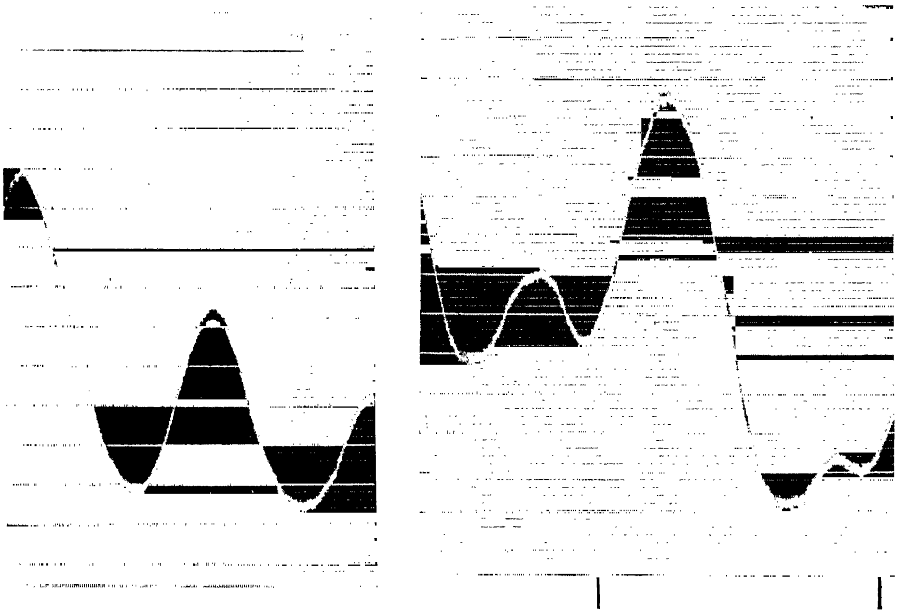


4730. A
Qz. L.P. (8 × 200 mm.).



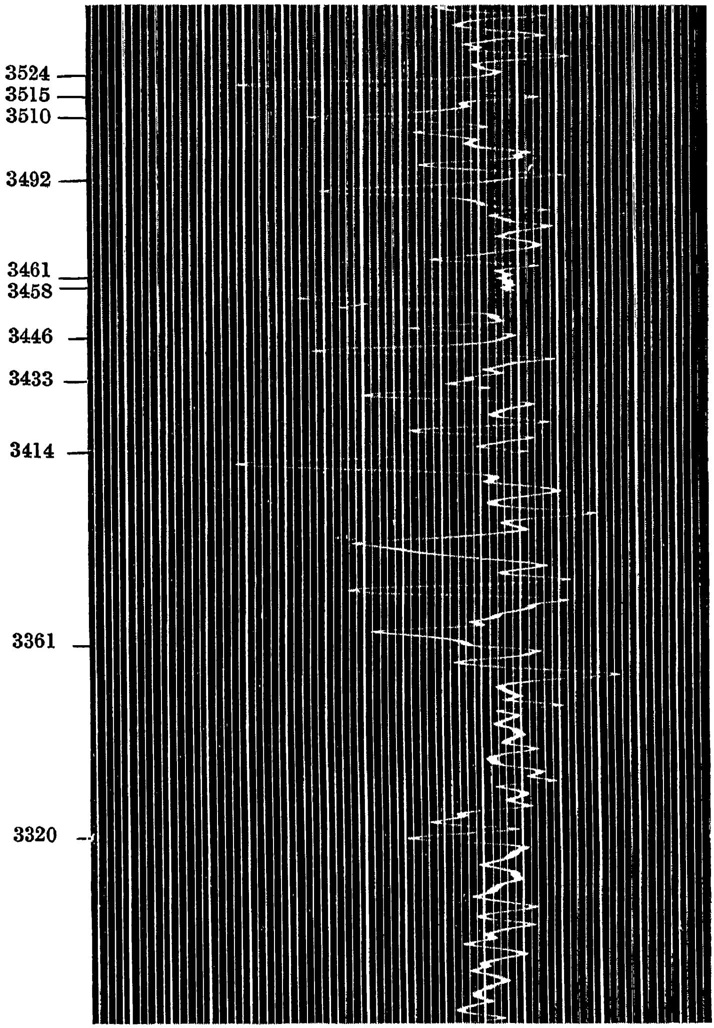
4888. A
Qz. L.P. (8 × 200 mm.).

FIG. IX (*b*).



5686. A

(*a*) Qz. L.P. (8 × 200 mm.) (*b*) Gl. L.P. (4·8 × 130 mm.).



Ni (U.W. ABSORPTION).
FIG. XI.

FIG. XII.

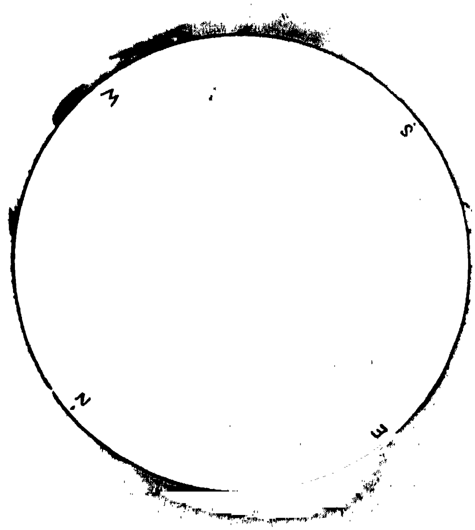


FIG. XII (a) Ca.

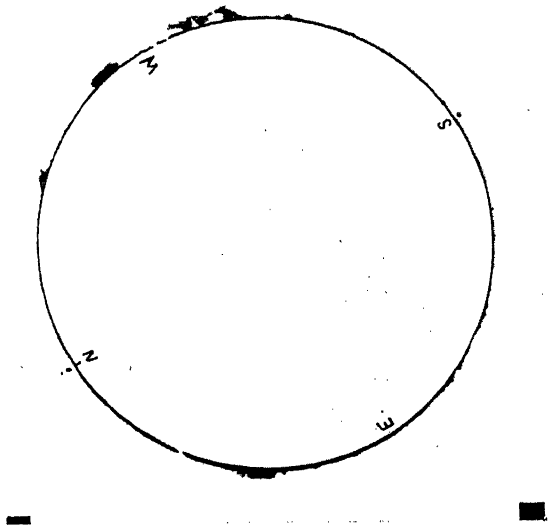


FIG. XII (a′) Hα.

FIG. XII(b) Ca.

FIG. XII(b′) Hα.

FIG. XII(c) Ca.

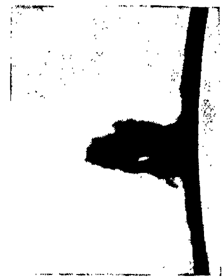
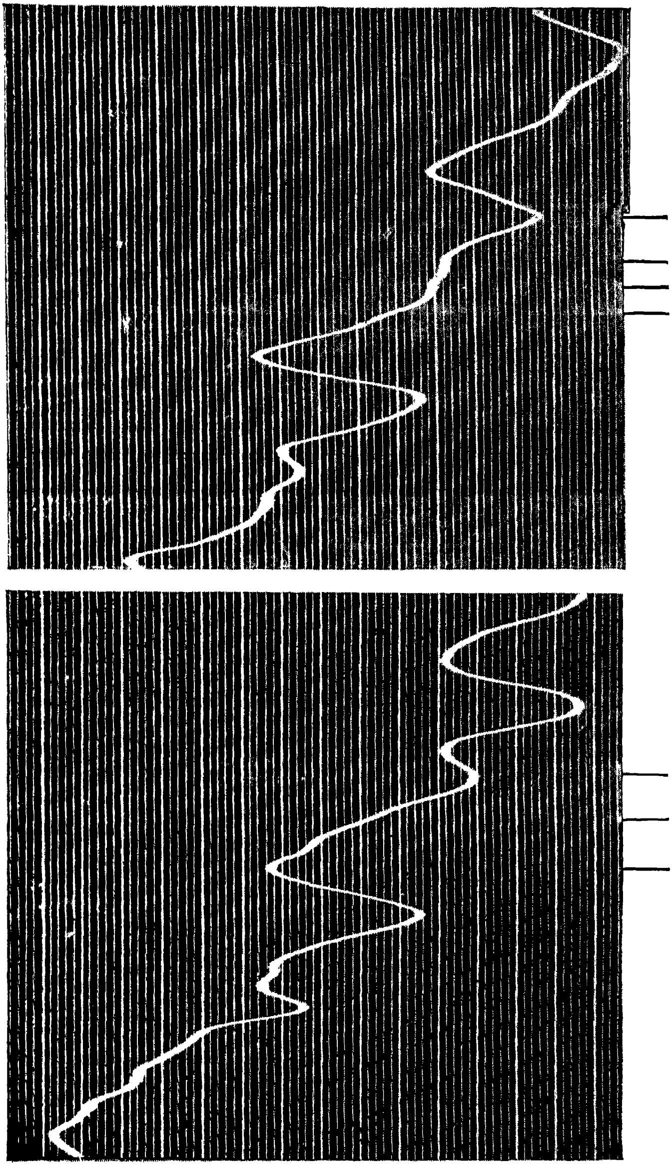


FIG. XII(c′) Hα.

By the kind permission of T. Royds.

FIG. XIII.



Qz. L.P.

5231 ($^3P_1$, $^3P_0$); 4985 ($^3P_1$, $^3P_1$).

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SOME SOLAR PROBLEMS

T. ROYDS, D.Sc., F.N.I.

Section of Mathematics and Physics.

President :—DR. T. ROYDS, D.Sc., F.N.I.

Presidential Address.

SOME SOLAR PROBLEMS.

Without the sun we should have neither food to eat, nor yet sufficient warmth to keep us alive. Although the sun is a vital necessity for the existence of all forms of organic life on this earth of ours, this is not the only reason why the physical constitution of the sun has been for long a question for detailed investigation by astronomers. The stars and planets have been a favourite object of study by mankind for untold centuries. Our later studies of the stars have called attention to the fact that in the stars physical processes are taking place under conditions which are not available in any earthly laboratory. In the interior of stars the atoms are exposed to temperatures and to radiation transcending any conditions which we can produce in the laboratory. If the properties of matter under these extreme conditions can be studied, we shall better be able to understand the properties of matter still mysterious to us in our laboratories, and perhaps be able to apply our understanding for the use and benefit of mankind. But whatever may be our ultimate reason for studying the stars, they are so far away from us and the light from them is so faint when it reaches us, that an intimate knowledge of them must always be a matter of difficulty. The stars are so far away that they appear to us as mere points of light and no telescope, however powerful, can bring them near enough to let us see their surfaces. We are however favourably situated as regards one star, namely the sun. We are so close to the sun that we can see its actual size in the sky. It is the only star whose surface we can study. The phenomena which we can see on the surface of the sun reveal to us the conditions prevailing in the outer envelopes of stars, which must have been hidden from us if we had not had the sun's surface available to us to reveal their possibilities. Whether or not it is a mere accident which has placed us near enough to one star to see its surface, our knowledge of the stars in general owes a great deal to the fact that we can make a detailed study of one of them.

In selecting the solar problems which I might bring to your notice I have been largely influenced by investigations made at the Kodaikanal Solar Physics Observatory in South India, and the problems I mention below are some of those which have recently occupied much of our attention in that Observatory.

The first problem relates to prominences. Let me recall, in a glance, the appearance of the sun's surface as it can be seen with modern instruments. The surface of the sun which we see with the naked eye, with or without a telescope, is called the photosphere. On this surface are seen the well-known sunspots, and we cannot see deeper into the sun, although it is entirely gaseous, than this surface. This photospheric surface emits a continuous spectrum corresponding to a temperature of 5740°K. Its spectrum is crossed by a large number of absorption lines, called, after their discoverer, the Fraunhofer lines. They are caused by an envelope some hundreds of miles thick, known as the reversing layer and consisting of most of the known terrestrial elements. At a total eclipse of the sun the moon gradually blocks out the sun's disc from our view, has advanced far enough to cover the photosphere completely, the reversing layer remains uncovered for a few seconds before it, too, is covered by the advancing moon. During these few seconds the reversing layer is seen without photospheric background and it consequently shows now as an emission spectrum, known, on account of its short duration, as the flash spectrum. Thereafter, a still higher envelope some thousands of miles thick, called the chromosphere because it is coloured, and a more extensive but fainter envelope called the corona, remain visible throughout totality. Outside of a total eclipse the corona cannot be seen, although some partial success in observing the corona in full sunlight has been claimed by Lyot. The chromosphere, on the other hand, can be seen and photographed by means of the spectroscope and of its applications as a spectroheliograph and a spectrohelioscope. The spectroheliograph, for example, can easily reveal the chromosphere in full sunlight, using the light of either ionized calcium or of hydrogen, by covering up the photosphere with a disc to make an artificial eclipse of the sun in order that a long exposure can be made on the chromosphere alone. Either by the spectroscope and its applications, or at eclipses, some prominences can always be seen extending to considerable heights above the chromosphere at different places on different days. The spectroheliograph can also reveal on the disc of the sun, dark markings which are quite distinct and different from sunspots. Ever since the discovery of these dark markings it has been recognized that they must be closely related to the prominences at the limb of the sun.

The Relation between Prominences and Dark Markings.

One of the problems which has been studied at the Kodaikanal Observatory has been the nature of these dark markings referred to above, and their exact relation to the prominences

at the limb. The majority of the dark markings are long and narrow, and lie in a direction inclined to the lines of longitude and latitude with the end nearer the equator more westerly than the end which is nearer the poles. Moreover, this average inclination depends on latitude. Those near the equator lie almost north and south but in higher latitudes they incline more and more with the polar end towards the east until in latitudes higher than about 40° they lie nearly east and west. The cause of this inclination is the polar retardation in the sun's rate of rotation. Since the higher latitudes rotate more slowly than the lower, the polar end of a dark marking will, as time goes on, lag behind the equatorial end. This is well shown by the long straight marking of August 1927 illustrated in Kodaikanal Observatory Bulletin No. 89. It crossed the central meridian on August 2nd inclined at 40° ; after a complete rotation of the sun it was again crossing the central meridian but with its inclination increased to 55°.

Apart from any other interest, the variation of the inclination of dark markings has proved a great practical convenience in studying them. For example, those lying along a parallel of latitude cannot be used for determining the speed of rotation of markings but those which lie in a direction approximately north and south give the most precise values. And again, the latter kind is useless for comparing with width of a dark marking with the width of a prominence whilst the former kind is more suited for this purpose. We shall see later on, that markings which lie neither north and south nor east and west, but in some intermediate direction, also have their uses.

Another feature of dark markings as shown in hydrogen spectroheliograms is the fact that on each side of the length of the dark markings, there is a bright margin. These bright margins are seen with greatest contrast when the marking is near the limb, but in this case the margin on the limb side is hidden behind the higher projecting dark marking. The relation of these bright margins is not yet completely understood. They are at a lower level than the dark marking, yet they are not evidenced in calcium spectroheliograms and are not shown in photospheric light.

That there is an intimate relation between dark markings and prominences has long been recognized and is shown by the two following facts: (1) a prominence is nearly always seen where a dark marking touches the limb, and (2) when a well-marked prominence has been seen at the east limb, a dark marking is seen on the disc after a few days. A problem we have tried to investigate at Kodaikanal is the exact relation between the two, the prominence at the limb and the dark marking on the disc. A great difficulty arises from the fact that when an individual prominence is compared with its associated dark marking, inconsistencies prevent much progress.

A time interval must elapse between the dark marking being visible on the disc and the prominence appearing at the limb and it would seem that changes and movements in this time interval thwart consistent comparisons.

Most progress in the comparing of dark markings and prominences has been made by considering averages, especially the average heights of the two phenomena. The height of a dark marking above the surface of the sun can be deduced either from its changing area as it approaches the limb, or from its apparent motion in longitude. If a dark marking lay flat on the sun's surface, its apparent area would decrease near the limb on account of foreshortening. The change observed is actually the contrary, namely the area increases near the limb compared with the centre. This increase is due to the fact that the dark marking has a height above the surface of the sun, and the rate of increase is a measure of the height. Mr. Salaruddin has given in Kodaikanal Observatory Bulletin No. 96 his measures of the rate of increase of the areas of dark markings as they pass across the sun's disc, and the average height of a dark marking above the surface of the sun he finds to be 31″. The average height of prominences at the limb is known to be about 36″, which is sufficiently good agreement with the height of a dark marking.

The other method of deducing the heights of dark markings depends on a discovery by d'Azambuja that they show an acceleration in the apparent speed of rotation when near the limb of the sun. Now the actual speed of rotation can be found from the time occupied by a complete rotation of the dark marking, and it is found to be about the same as the speed of sunspots. The apparent acceleration near the limb was interpreted by d'Azambuja as due to the height of the dark marking above the surface of the sun and he deduced their height from measures of the apparent longitudes near the limb. It is my experience that measures of longitude near the limb are subject to large errors, and consequently I have found it more convenient to measure the time required for a dark marking to pass from the central meridian to the limb, and vice versa. Dark markings which lie in directions between north (or south) and east are most suitable for these measures. It is a simple matter to measure the latitude where such a dark marking meets the limb at the time when a photograph was taken. The time when this part of the marking was exactly at the central meridian can be deduced accurately from the photographs taken when the marking was near the central meridian. The time interval required to pass from the central meridian to the limb, I have called the quadrantal time for the latitude measured. If a dark marking lies flat on the surface of the sun the quadrantal time would be exactly one quarter of the time required for a complete rotation. Now a complete

rotation (synodic) of a dark marking takes 27·27 days, and a quarter of this is 6·82 days. The quadrantal times are however less than this by an amount which measures the height of the dark marking above the surface of the sun. The average quadrantal time found is 5·55 days, that is it requires one and a quarter days less for a dark marking to pass from the central meridian to the limb, and vice versa, than for a quarter rotation of the sun. This corresponds to a height of 33·5″ above the surface of the sun, a value which again is in surprisingly good agreement with the average height of prominences at the limb. The result mentioned above applies to the edge of a dark marking which is nearer the limb than the centre. This is the highest part of the dark marking. The other edge, which is nearer the centre than the limb, corresponds to the lowest part of the marking. It is surprising to find that the quadrantal time for this edge implies that it is at a considerable height above the surface of the sun; indeed the bottom of the marking is only 5·5″ below the top. This has not yet been fully explained but I believe that the cause lies in the way the measures have been taken, namely that whilst they give the highest part of the marking correctly, they tend to select as the lowest part portions which are not actually reaching down to the surface of the sun.

Some further measures are at present being made at Kodaikanal which will help to trace the connection between dark markings and prominences, but so far as the above results go, the evidence shows that the dark marking and the prominence are merely different aspects of the same identical solar phenomenon. Perhaps this may seem a somewhat tame conclusion of what was only to be expected. Yet anyone who has endeavoured to trace the connection the individual prominence and its associated dark marking would, I think, find that their identity was by no means obvious. If we are convinced of the identity of prominences and dark markings, the prominence being a kind of profile at the limb and the dark marking being a kind of projection on the disc, so that the two are merely different aspects of the same feature of the sun, it follows that the typical characteristic of this feature consists of a narrow line of flame extending along a considerable length of the sun's surface. This line of flame has a width of about 7,000 miles, an average height of 14,000 miles, but of a length enormous compared with these dimensions and often amounting to 400,000 miles or more.

The Support of the Sun's Chromosphere.

Another solar problem to which we at Kodaikanal have devoted much attention is the question of the supporting force of the chromosphere. The chromosphere extends to heights

far greater than can be supported by gas pressure. The height of the chromosphere can be measured in various ways. One method is to measure the distance of the top of the bright hydrogen line in an undisturbed part of the chromosphere above the continuous spectrum. This gives a result of the order of 10″, or 7,250 kms. Another is to measure the diameter of spectroheliograph images of calcium or hydrogen light compared with the diameter of the image taken with the neighbouring continuous spectrum; for hydrogen this gives a height of 6·3″.

The measures which are obtained at total eclipses give heights which are greater than these because the glare of bright sunlight without an eclipse prevents the upper limit of the chromosphere as revealed during an eclipse from being reached. The greatest heights for the chromosphere are therefore recorded at eclipses. These heights are measured from the lengths of the chromospheric arc with the objective prism, or by the length of the line on a falling plate. The height reached by any particular line varies at different eclipses, but the greatest heights have been recorded by Mitchell in the eclipse of 1905; the height reached by ionized calcium was 14,000 kms. and by hydrogen 10,000 kms.

It had long been a difficulty to explain how chromospheric gases could be supported to such great heights against gravitational forces. If the supporting force were gas pressure the density of hydrogen at a height of 10,000 kms. would be 10^{-25} times that at the base, less than one atom per c.c., and above this height there would not be one atom of calcium per sq. cm. Indeed the thickness of a chromosphere which could be supported by gas pressure would not exceed 100 kms. Consequently it is evident that gas pressure is totally inadequate to explain the great heights recorded in eclipses.

The effectiveness of selective radiation pressure was first suggested by Saha. Milne has shown that the selective radiation pressure can be calculated in the case of ionized calcium and was adequate to support a calcium chromosphere. Milne's theory briefly is as follows. When an atom absorbs a quantum of radiation, the average upwards momentum communicated to it is $\frac{1}{2}h\nu/c$, and the atom will be driven upwards. By the absorption of other quanta, more atoms will be driven upwards and will partly screen the first atom from the full force of the photospheric radiation. This process will continue until the atoms at the top have been so much screened that the radiation pressure just counterbalances the force of gravity. There are three conditions which must be fulfilled for selective radiation pressure to be effective in supporting a chromosphere: (1) the line absorbed by the unexcited atom must be in the visible region where the sun is radiating strongly, (2) the life of the atom in the excited state must not be too long or the atom will fall before it can absorb another quantum, and (3) atomic

collisions must be infrequent. Milne has shown that on account of the simplicity of the atomic states which have to be considered, the case of ionized calcium lends itself to exact calculation. Milne has calculated the density law for ionized calcium supported by radiation pressure and finds that the density is inversely proportional to the square of the height above some fixed level. The density at a height of 8,000 kms. would be one-third of that at the base, and at a height of 15,000 kms. would still be only $\frac{1}{87}$ of the density at the base. Milne therefore finds that the selective radiation pressure theory is adequate to explain the great heights reached by calcium in the chromosphere.

The theory may also explain the formation of prominences by the increased thickness of the chromosphere due to increased local radiation from the photosphere below the prominence. Further, as first pointed out by Sur, the eruptive prominences which are occasionally observed may be explained by the intensified radiation from below being sufficient to overcome the gravitational attraction so that the calcium atoms are driven away from the sun. Milne has shown that a small velocity of ascent would, by a Doppler shift of the absorption towards the violet, increase the background of radiation to which the atoms in the chromosphere are exposed, resulting in an ever-increasing upward velocity of the calcium atoms until they were exposed to the full force of the photospheric radiation outside the calcium lines.

Milne's theory is very attractive, and is in fact the only theory which can in any way adequately explain the observed phenomena even to a limited extent. Nevertheless Milne's theory fails completely in certain respects. The main difficulty is the question of the existence in the chromosphere of other elements than ionized calcium. The theory, as it has been so far developed, can offer no explanation for the normal presence of hydrogen and helium in the chromosphere and in prominences. Let us examine the case for radiation pressure on hydrogen, for example. The unexcited H atom absorbs light of wave-length 1216A, a region in which the sun's photospheric radiation is very feeble. The number of H atoms which can be supported is therefore small, and of this number only a minute fraction can be in a state to absorb the Balmer lines which are the only lines falling within the region where the sun is radiating strongly. Similar, but still stronger, reasons apply in the case of atoms of helium. The radiation pressure theory therefore fails completely to explain the normal presence of H and He at great heights in the chromosphere. The failure is also complete in the case of prominences. The evidence is clear that hydrogen extends in prominences to the same height as calcium. Not only at Kodaikanal, but at Mt. Wilson also, prominences have been regularly photographed in the light of both hydrogen and

calcium. All observers have come to the conclusion that prominences are, essentially, of identical appearance in both hydrogen and calcium. The same is probably true of helium, as can be seen from eclipse photographs. Even when we study eruptive prominences, where the calcium prominence is ascending above the sun's surface with enormous velocities, the evidence, so far as it goes, shows that the height, size, shape and consequently motion, is identical for both hydrogen and calcium. So it would appear that the force lifting up the prominence must be identical on both hydrogen atoms (in the 2 quantum state) and on ionized calcium. It is almost inconceivable that the radiation pressure on two different elements, especially on two whose absorption lines are produced in very dissimilar ways, can be so nearly identical as to show no separation of the two elements in prominences. When we add that the same must apply to a third element, helium, also we begin to appreciate the real difficulties in the way of the radiation pressure theory.

These considerations led me to search for the existence of another element in chromosphere whose presence, if demonstrated, would be a further obstacle in the way of the radiation pressure theory, albeit an obstacle of the same nature as that just considered. Modern atomic theories have enabled progress to be made in interpreting the intensities of spectrum lines in terms of the number of atoms of the element concerned. The first steps in representing the proportion of the different atoms which are present in the sun have been made by Russell. The number of atoms of the metallic elements present in the sun can be stated with some precision, but the data for some of the non-metals are subject to considerable uncertainty. In spite of this, Russell has made an estimate of the composition of the sun. He finds that hydrogen is the most abundant element in the sun, helium and oxygen next, and the metals a long way behind. His figures are hydrogen 92 per cent. by volume, helium 3 per cent., oxygen 3 per cent., all metals $1\frac{1}{2}$ per cent. to which calcium (both ionized and neutral) contributes $\frac{1}{17}$ per cent. Far more abundant then than calcium are hydrogen, helium, and oxygen. The first two are present in the chromosphere, so why not oxygen also ? Oxygen is represented in the sun by only five lines in the infra red, of which the most accessible is the triplet at 7771, 7772, and 7775A. Since photographic plates which are sensitive to infra red light are available in the market it should be possible to test for the presence of oxygen in the chromosphere without waiting for a total eclipse of the sun. The results obtained have been published in Kodaikanal Observatory Bulletin No. 107. It was found that oxygen is a normal constituent of the sun's chromosphere, and that since the infra red triplet is produced by the excited atom of oxygen, the number of unexcited atoms present in the chromosphere

must be large. Again, since the absorption by the unexcited O atoms lies far in the ultra-violet the force exerted by radiation pressure must be infinitesimal.

There is also evidence that the Milne's original estimates of the weight of ionized calcium which can be supported by radiation pressure has been grossly over-estimated, since the width of the absorption line which is available for supporting by radiation pressure is much less than originally supposed.

Notwithstanding the beauty and simplicity of Milne's theory, it must be realized that there are grave obstacles still to be overcome. An attempt has been made to invoke the idea of turbulence to explain how the support exerted on calcium is communicated to other elements. The idea seems to be based on a misconception of turbulence. It is impossible to conceive of turbulence in a region where atomic collisions are infrequent. The mean free paths in the chromosphere are so long that the interval between collisions must be reckoned in minutes, if not in hours. Since collisions rarely occur there can be no turbulence, in the ordinary sense, tending to mix atoms of different kinds.

Electrical forces have also been considered and rejected, principally because these forces could only operate on ionized atoms and not on neutral hydrogen or helium.

Considering the fact that calcium only contributes a small proportion to the composition of the sun, and yet does actually reach to heights in the chromosphere greater than those which are far more abundant, it would seem that the rôle of selective radiation pressure on ionized calcium is not by any means a negligible one. Alone of the more abundant elements in the sun is ionized calcium subjected to any reasonable radiation pressure, and it is precisely this element which attains heights as great as, and even greater than, any other. Consequently it would seem that the unknown force which supports the chromosphere begins to operate at a height above that reached by the most abundant metals in the sun, but finds at this height a disproportionate quantity of ionized calcium which has been raised there by virtue of radiation pressure. In this unsatisfactory state we leave the problem, hoping that a way will be found of adapting Milne's theory, which is of singular simplicity and beauty, to account for the facts which at present it fails to explain.

MICROPHOTOMETRY OF FRAUNHOFER LINES.

New ideas of the method of formation of absorption lines have led to the necessity for much work on measuring the intensity of light within absorption lines. It is necessary to obtain not only the distribution of light within the absorption line, but also the total amount of light absorbed in the line.

At Kodaikanal we have recently turned our attention to the microphotometry of some of the stronger lines in the sun's spectrum, principally the lines of calcium and of hydrogen.

Nearly all attempts to measure intensities in spectrum lines depend on first obtaining a photograph of the spectrum, and then interpreting the varying densities in the plate in terms of intensity. In this interpretation, the peculiar properties of photographic plates are involved. The densities in a negative are, for a considerable range, proportional to the logarithm of the intensities of the light falling on the plate. The factor of proportionality for any particular plate is dependent on the developer used and the time of development. But it is known that even within the region of proportionality of density to the logarithm of intensity, the density also depends on other factors, such as the wavelength of the light and on whether the exposure is intermittent or continuous. It is also known that the so-called reciprocity law fails, namely that equal values of the product of exposure time and intensity do not yield equal densities.

These peculiar properties of photographic plates necessitate the adoption of certain precautions in obtaining photographs for photometry. In order to eliminate the effects of properties which are difficult to determine exactly, and which vary from plate to plate, there is only one property which can safely be trusted, namely that equal intensities from two sources emitting the same wavelength will give equal densities on the same photographic plate when the conditions of exposure and development are identical. If the durations of exposure are not the same, some allowance which cannot be determined very exactly has to be made, and if the wavelengths are not the same, we have in some way to make allowance for the varying behaviour of the plate with wavelength. The only safe procedure for calibrating the intensities in a photograph is to give the same exposure on the same plate to a standard source emitting the same wavelength. Even then special precautions have to be taken in the development of the plate, for Eberhard has found that there is local exhaustion of the activity of a developer in those regions of the plate where the density is greatest. One way of minimizing the Eberhard effect is to develop with a brush which sweeps out of the emulsion the byproducts of the developer retarding development of the well-exposed parts of the emulsion.

So with every spectrum plate which has to be photometered it is necessary to imprint on the same plate and with the same exposure, other standardizing spectra in which the intensities have been varied in some known manner to cover the range of intensities which are to be measured. The most usual way of varying the intensity in the standardizing spectra is by the use of an absorption wedge across the spectrum, either a wedge which produces a gradual weakening, or a step wedge which

weakens the intensity in the standardizing spectrum by known steps. The calibration of the wedge employed calls for some care. It is not very difficult to measure the opacity of the different steps of a step wedge but it is necessary to take into account the fact that the opacity depends on the way in which the wedge is used. The opacity of a wedge placed in a beam of parallel light is different from the values obtained in non-parallel light by an amount which depends partly on the graininess of the absorbing medium of which the wedge is constructed. At Kodaikanal we have used step wedges made from photographic plates as being very convenient in use, but it has been found, for example, that the opacities of the same wedge are vastly different when the wedge is used in front of the spectrograph slit from those when the wedge is used immediately in front of the photographic plate. It is of primary importance, therefore, that the opacities of the wedge should be determined in the position in which the wedge is to be used. This has been done at Kodaikanal in two ways, the first by interposing perforated screens in the optical path and the second by comparing the densities given by the step wedge with those produced by a standard wedge used in the manner for which it was standardized. The wedge steps must be determined over a range of wavelengths in which it is to be used, for most wedge opacities vary slightly with wavelength.

The problem of spectro-photometry is now reduced to one of measuring the densities in different parts of the spectrum plate. Various types of photometers are available in the market for density measurements. The most common forms of photometer measure the amount of light passing through the plate from a steady lamp on to a thermocouple or a photoelectric cell. For spectrum measures it is necessary that the light should pass through a very narrow slit parallel to the spectrum lines in order to obtain a sufficiently high resolving power. At Kodaikanal we have used the Cambridge Instrument Company's microphotometer which employs a photoelectric cell, the varying current passing through the cell being recorded on bromide paper by the shadow of an electrometer. This instrument has proved very reliable in practice, for it is found to have a steady zero and to give the same deflection under the same conditions when proper precautions are taken.

Let us now consider briefly the formation of an absorption line by an absorbing atmosphere such as we have in the sun's reversing layer. It has been pointed out by more than one investigator that the term 'absorption' line is really a misnomer. True absorption means the process whereby an atom, having reached an excited state by the absorption of a quantum of light of appropriate wavelength, returns to its former state by a super-elastic collision with another atom without the emission of light, but with an increase in the kinetic energy

of the atoms. True absorption is the exact reverse of emission by thermal excitation. In thermal emission atomic collisions raise the atom to an excited stage at the expense of the kinetic energy of translation. What is commonly termed an 'absorption' line is rather believed to be caused by the scattering of light from the photosphere by the atoms present in the atmosphere. In scattering, a quantum of light of suitable wavelength is absorbed by an atom which returns to its former state by re-emitting a quantum of the same wavelength in all directions. An 'absorption' line is formed in the light emerging through the scattering atmosphere because only a portion of the light scattered is re-emitted in an outward direction.

We must now consider what are the causes which make absorption lines have appreciable width. We need consider, in the sun's absorbing atmospheres, only three causes of broadening: First, the Doppler broadening due to the movements of the absorbing atoms; second, the Stark effect or broadening due to inter-atomic electrical fields which probably includes the broadening due to pressure; and third, abundance broadening. This latter is of special importance. A formula for the abundance scattering coefficient was given by Voigt and was first applied by Unsold to determine the numbers of atoms in the sun's reversing layer. This abundance scattering coefficient is given by

$$\sigma=\frac{2\pi e^2}{3m^2c^4}\cdot\frac{\lambda_0^2}{(\lambda-\lambda_0)^2}\cdot Nf$$

where σ=the scattering per cm. length,
λ_0=wavelength at the centre of the absorption line,
N=number of absorbing atoms per c.c.,
f=oscillatory strength for this particular line,

and the remaining terms have their usual significance.

Now it has not yet been found possible to give an exact expression for the contour of an 'absorption' line produced by scattering in an atmosphere of finite thickness. The best which can be done at present is to use approximations made under simplifying assumptions. Schuster showed that if we assume a definite photospheric surface underneath a homogenous scattering atmosphere, the contour of the resulting 'absorption' line will be given by

$$r=\frac{1}{1+\sigma H}$$

where r=ratio of intensity in the line to the intensity of the photospheric radiation,
σ=scattering coefficient of the atmosphere,
and H=the height of the atmosphere.

The number of scattering atoms in an atmosphere can be most conveniently deduced by measuring the total amount

of energy 'absorbed' from the photospheric background. This is called the equivalent width of the line, and is expressed as the wavelength range of the continuous spectrum which is absorbed in the whole width of the line; i.e. an equivalent width of 1A means that the absorption line prevents the energy included in 1A of the continuous spectrum from passing through the atmosphere. The equivalent width of a line is therefore measured by $\int_{-\infty}^{\infty}(1-r)d\Delta$, where $\Delta=\lambda-\lambda_0$. In the case of abundance scattering and using Schuster's approximation, Unsold showed that the equivalent width (W) of a line is proportional to the square root of the number of scattering atoms above unit area of the photosphere, namely

$$W=\frac{\pi e^2}{mc^2}\cdot\lambda_0\cdot\sqrt{\frac{2\pi}{3}}\cdot\sqrt{NfH}.$$

When however the width of a line is controlled by collision scattering, the scattering coefficient follows an entirely different law and the corresponding equivalent width is then given by

$$W=\frac{\pi e^2}{mc^2}\cdot\lambda_0^2\cdot NfH.$$

In the case of an actual solar atmosphere where both kinds of scattering are operating simultaneously, the first formula will give an upper limit to the number of scattering atoms, and the second a lower limit.

Let us pause a moment to consider the conditions for the centre of the absorption line. Here the collision damping has least effect and only the radiation damping is effective. We can consequently use the scattering coefficient given above. It is seen that, according to the formula, the scattering coefficient for the centre of the line $(\lambda-\lambda_0)=0$ becomes infinite and the absorption of the photospheric radiation should be complete, i.e. $r=0$. Now it is well known that the central intensity of even the most intense of the Fraunhofer lines is not zero, in fact spectroheliograms are obtained daily with the light in the centre of Fraunhofer lines, and in them we see the familiar features due to varying intensities in the centre of the line at different parts of the sun's surface. Some attempts have been made by Woolley and Strömgren to explain the appreciable central intensities which are found in the Fraunhofer lines but their postulates have not yet been sufficiently tested.

The estimates of the numbers of atoms in the sun's reversing layer have been first made by Unsold, and his results are well known. At Kodaikanal we have been engaged in measuring

the changes in the contours of absorption lines as we pass from the centre of the sun's disc to the limb. At the sun's limb we are looking through the sun's atmosphere at an angle inclined to the sun's radius. As we pass from the centre of the disc to the limb, the number of atoms in the path of the photospheric radiation would be expected steadily to increase, and consequently the widths of all lines should steadily increase. This is however not what is actually observed and the discrepancy cannot be ascribed to the deficiencies of the Unsold theories of scattering. Let us look, for instance, at those absorption lines in the sun's spectrum which are produced by the earth's atmosphere. Examples of these are the A and B bands in the sun's spectrum. When the sun is low in the sky these lines are considerably broadened compared to when the sun is high. In fact, they form a very valuable confirmation of Unsold's law for abundance scattering. Since the temperatures in the earth's atmosphere are comparatively low, the Doppler effects are small and the conditions may therefore be taken to be those of pure abundance scattering, for which Unsold's law should strictly hold. From photographs taken at Kodaikanal we have confirmed results obtained elsewhere that the equivalent width of the B band in the solar spectrum increases proportionately to the square root of the length of path of the sun's rays through the earth's atmosphere, i.e., proportional to $\sqrt{N}$ exactly as required by Unsold's law.

When however we turn to the sun, we find that the width of the absorption lines actually diminishes as we approach the limb of the sun, which is entirely opposed to what one might have expected. It is the consideration of the cause of this which has led us to new conclusions regarding the number of atoms in the sun's reversing layer, and particularly to the lower portions of that layer. Whatever may be the theory of formation of absorption lines which we prefer to adopt, the evidence of the sun's spectrum leads to the conclusion that the number of atoms down to the depths to which we can see is greatest for the centre of the disc. Notwithstanding the fact that at the limb the line of sight is more inclined to the sun's radius, the depth down to which we can see at the limb contains fewer atoms than when we look at the centre of the disc. The cause for this reduction in the number of absorbing atoms is ultimately the same as the cause of the darkening of the sun's limb in white light. The limb of the sun is less bright than the centre of the disc, and it is commonly accepted that the cause of the darkening at the limb is the fact that there we reach complete opacity at a higher level than when we look at the centre of the sun, on account of the greater inclination of the line of sight at the limb. The greater length of the inclined line of sight at the limb prevents us from seeing so deeply into the sun. Consequently at the limb we see the continuous

spectrum radiation from a layer which is not so deep as, and therefore cooler than, the layer to which we see at the centre of the sun's disc. So that when we are measuring an absorption line at the sun's limb, we are measuring the number of atoms above a higher layer than when we measure at the centre of the disc, albeit along a more inclined path. We have therefore two opposing tendencies at the limb of the sun; the longer path due to the more inclined line of sight tends to increase the width of the spectrum lines, and the shorter depth to which we can see down into the sun's atmosphere decreases the width. The evidence shows that the latter tendency predominates. We can allow for the increase in the path through the atmosphere from geometrical considerations, but we still have to estimate the depth into the sun's atmosphere to which we can see at different parts of the sun's disc. The simplest way to estimate this seems to be from the temperature gradient in the sun. Eddington has given formulæ for the temperature gradients which should apply to that part of the atmosphere which we are now considering. Essentially it comes to the same thing as the temperature gradient which will explain the darkening of the sun's limb in white light. From these values we have deduced, by means of the measurements made at Kodaikanal, estimates of the densities of calcium and of hydrogen in the lower parts of the sun's reversing layer. These results are :—

neutral calcium	$7{\cdot}8 \times 10^{10}$ atoms per c.c.
ionized calcium	$2{\cdot}1 \times 10^{13}$ atoms per c.c.
hydrogen (2 quantum) ..	$3{\cdot}4 \times 10^{10}$ atoms per c.c.

From these values we can deduce their partial pressures and that of electrons. The data apply to the lowest parts of the reversing layer.

In this way we have applied the principle that the equivalent widths of absorption lines are a measure of the number of atoms in the solar atmosphere, and have deduced the physical conditions obtaining in the lowest parts of the reversing layer. The interpretation of photometric measures still requires the solution of several problems relating to atomic theory, namely the problem of the appreciable intensity at the centre of absorption lines, the problem of radiation passing through an atmosphere of finite thickness, the problem of the discrepancy between observed contours of absorption lines and theory, and also the problem of the great intensity of the Balmer lines.

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NOTICE

The Executive Committee of the Indian Science Congress Association have decided, with the approval of the Council, to confer the honour of Honorary Silver Jubilee Membership upon the following:

Sir Prafulla Ray	..	One of the pioneers of scientific research in India, who created the Indian School of Chemistry.
Sir M. Visvesvaraya	..	A distinguished engineer and a past administrator of one of the most progressive Indian States, who has done much for the application of Science to Industry.
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Prof. J. L. Simonsen	..	One of the founders of the Indian Science Congress, its General Secretary for twelve years, and a distinguished chemist.
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Prof. C. G. Jung Prof. L. F. de Beaufort	.. ..	Distinguished representatives of Non-British Science.

The Diplomas of Honorary Silver Jubilee Membership will be presented to the recipients by His Excellency the Viceroy at the Opening Meeting on January 3rd.

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Mitra, Dr. Subodh, M.D., F.R.C.S.	...	1/2, Gokhale Road.
Mukherji, Sunil Kumar	...	12A, Bakul Bagan Row.
Majumdar, Dr, Subodh K. M.Sc., Ph.D.	...	Presidency College, (Chem. Dept.)
Mitra, Subhendra K. M.Sc., PhD.	...	P.O. Dhakuria, 24 Parganas.

Names.		Local Addresses.
Madhava Rao, Dr. T. V.	...	C/o D. N. Wadia, Geological Survey of India.
Mitra, Sisir K.	...	54, Keshab Chandra Sen St.
Mitra, Dr. B. N., D.Sc.	...	A. I. H.
Mookerjee, H. N., A.M.A.E.	...	P177, Lake Road.
Mukherjee, S.	...	Dept. of Biology Medical Coll,
Muhl, Dr. Anita, B.S. M.D., Ph.D., F.A.C.P.	...	1, Middleton Row.
Mullick, D. N.	...	60, Kalutola Street.
Mehta, Dr. (Miss) M. M.	...	C/o J. J. Modi Esq. 8, Dharramtala St. B. Block.

N

Nenarwala, M. P.	...	Canning Hostal.
Naolekar, G. G.	...	M
Nath, Madhab Ch.	...	135, Bowbazar Street.
Neogi, Sukumar	...	21, Kundu Lane, Belgachia.
Nandan, Nepali, A.	...	103/3, Lower Chitpur Road.
Naidu, D. S.	...	Govt. Test House, Alipur.
Napier, Dr. L. E.	...	T
Narashingham, V.	...	D
Neste, Rev, J. Van, S. J.	...	Prof. St. Xavier's College. 30, Park Street.

P

Poduval, R. V.	...	C/o Dr. Stella Kramrisch. Lecturer, Cal. University.
Pendse, G. P.	...	D
Purushottam, T. A. Dr.	...	
Purushottam, A.	...	D
Panja, G.	...	T

Names.		Local Addresses.
Padmanavam, N.	...	
Prasad, Mrs. Baini	...	Indian Museum.
Prokash, S ıtya, M. B.	...	28/2, Cornwallis Street.
Puri, Mr. N. L.	...	100, Clive Street.
Pandit, Dr. Sharyu, M.B.B.S., D.M.C.W.	...	A. I. H.
Patil, Miss Hira	...	C/o Prof. Agharkar.
Parvathiamma, K. (Miss)	...	C/o Miss S. John M. A. Continental Hotel.
Pillai, G. P. Entomologist.	...	6, Omda Raja Lane.
Panse, V. G.	...	M
Prayag, S. H. Rao Shahib	...	M
Pillay, Dr P. Parameswaran	...	D

R

Roy, D. N. M.D., Asst. Prof.	...	T.
Roy. Dr. H. L.	...	P. O. Jadabpour College.
Relvani, (Mrs) R.M., M.A.	...	2/1, Lovelock Street.
Ray, Kumar Sarat Kumar.	...	1/4, European Asylum Lane.
Roy. Mihir Bejoy	...	Do
Roy, Dr. B.B., L.M.F.	...	6, Omda Raja Lane.
Ray, Dhirendra Nath M. Sc.,	...	57, Chittaranjan Avenue (South).
Rao, Laksmi Narayana	...	Women Hostel.
Raman, P. K. C/o P. K. Seshan Esq.	...	210, Bowbazar Street.
Rao, Rao Bahadur D. Ananda, C/o S. C. Mukherjee Esq.	...	76B, Chakrabere Road.
Rao, S. Krishna,	...	D.
Rao, C. Bhashyakarla,	...	D.

Names.		Local Addresses.
Rao, S. Srinivasa.	...	76, Central Avenue.
Ramakrishnisa, D.	...	D.
Rahman, Wahidur.	...	4, Circus Avenue.
Rao, A. Nagaraja	...	D.
Rai, Shabib. Rakshit, J. N.	...	P 653, Rash B. Avenue.
Raghavan, Mr. M.D.	...	118, Armanian Street.
Rao, R. Madhab	...	P88, Monahar Pukur Road.
Rami Reddi, K.	...	D.
Ray, Dr. P. N. F.R.,C.S.	...	Medical College Hospital
Ray, Charubrata B.Sc., M.B.	...	13, Hindusthan Road.
Ranganatha Rao, V. N.	...	Arya Nibas.
Ramaswamy, C.M.A.	...	Asst. Meteorologist Meteorological office, Alipur.
Ray, A. C.	...	T.
Ray, Samarendranath, M. Sc.,	...	Statistical Laboratory. Presidency College.
Roy, Taresh, M.Sc.,	...	153/3L, Upper Circular Road.
Roy, Gunendra Krishna, Chemist	...	A. I. H.
Rangaswamy, S.	...	P, 136, Parashar Road.
Roy, Hem Chendra, M.A., P.h.D.	...	P39,A Manicktolah Squr.
Roy, Purna Chendra, Curator, Geological Survey.	...	27, Chowringhee Road.
Rudra, Manindranath. M.Sc.	...	12, Anath Deb Lane.
Ramsay, G.C., C.I.E., O.B.E., M.D.	...	C/o Mr. Leod House, Dalhousie Square.
Roy, Dr. S., M.B., M.Se., F.R.C.S. D.L.O.	...	8, Esplanade East.
Roy, Capt, S .K., M.B.	...	2, Amherst Street.

S

Sahni, Ruchi Ram, M.A.	...	C/o Dr. M. R. Sahhi Geological Survey.
Sahhi, Mrs. Shyama, B. A.	...	"

Names.		Local Addresses.
Sen, Satindra, K., Asst. Prof.	...	1, Belgachia Road.
Sil, B. C., M.Sc., Station Engineer.	...	35/1, Pack Para Road, Cossipore.
Sen, Mrinal Kanti, M.Sc.	...	17, Harrison Road.
Sinha, Suresh Chandra M.B., F.R.E.S	...	Prof. Medical College.
Swaroop, Satya, M.A.F.S.S.	...	Asst. Prof. A. I. H.
Sen, Jyotilal, M.C., Lt. Col. I. M.S.	...	250, Park Street.
Sarkar, Rishindranath, M.A. B.L.	...	20B, Sankaritola Lane.
Sengupta, Satya Ranjan M.S.c., Ph.D.	...	24, Harrison Road.
Sen, Dr. Profulla Kumar, M.D. Ph.D., T.D.D.	...	65A, Dharamtolla Street.
Singh, Mr, Gopal, M.Sc.	...	C/o R. L. Badhwar, Suite No. 5 44, Central Avenue.
Sen Gupta, Dr. Suresh Ch. D. Sc.	...	Presidency College. Chemistry, Dept.
Sarkar, Susobhan Chandra	...	Prof. of History, Presidency College.
Sen, Balaram	...	19/6 Nayanchand Dutt Street.
Singh, Karama	...	D.
Sen, Haripada	...	Jadabpure College.
Sen, Parimal Bikas	...	1/A, Preonath Banerjee Street.
Sinha, J. M. C/o Mr. A. Bholanath,	...	18, Gariahat Road.
Sen, D. N., M.Sc.	...	6, Narendranath Sen Square.
Sinha, Prof. S.	...	109, Grey Street.
Srivastava, B. N.		
Sen Gupta, Dr. A., M.B., D.T.M.	...	59/1, Hindusthan Park.
Sen Gupta, Dr. Prabhat K.	...	4/1, Beadon Row.
Sadasivan, T. S.	...	D
Savanur, P. K,	...	D

Names.		Local Addresses.
Sundararajan, R.	...	D
Sen, S. C.	...	16/1, Jadunath Dutta Lane.
Sen, Upendra Kumar,	...	16, Rammohon Saha Lane.
Singh, Jugal	...	22, Strand Road.
Sinha, S., Prof.	...	35, Badridas Temple Street.
Sen, M.	...	8, Bosepara Lane.
Sen, R. N., Ph.D.	...	5B, Mohanlal Street.
Subba Ramiah, K., M,Sc.	...	Test House, Alipur.
Seth. B. R. Dr.	...	
Sarin, Dr. J. L.	...	D
Saha, Charu Ch. M.Sc., M.B., D.T.M.		53, Belgachia Main Rd.
Sen Gupta, M.	...	Prof of Electrical Engineering B. E. College, Sibpur.
Sen, Dr. A. K.,	...	Director Public Health Lab.—T.
Sinha, Mr. S. N., M.A.	...	16/1, Sastitala Road.
Sarkar, Prof Benoy K.	...	45, Police Hospital Road.
Sen Gupta, Pabitra K.	...	Pharmacolagy Dept.—T.
Shastri, Dr. P. D., M.A., Ph.D. I. E. S.	...	34, Rowland Road.
Shastri, Mrs. Tara		" "
Senior White, R., F.R.S.E., F.R.E.S.	...	Medical Dept. B. N. Ry. Kidderpore.
Srinivasan, N., M. A.	...	Chemist, Shalimar Paint Varnish Co., Howrah.
Sinha, Purna Ch.	...	145/1, Baranoshi Ghose St.

V

Venkataraman, Mrs. K.	...	C/o Dr. Krishnan, A. I. H.
Venkataraman, S.	...	D

Names.		Local Addresses.
Verma, Mr. M. R., M.Sc.	...	Chem. Asst., Govt. Test House, Alipur.
Varghese, M. V.	...	15, Circus Row, Park Circus.
Virkki, C. (Miss)	...	Women Hostel.

W

Weltheim, Baron Von.	...	T C/o Lt. Col. R. N. Chopra.
Walker. Mr. H., M.P.S.	...	11, Clive Street, (Managing Director, May & Baker (India) Ltd.).

Y

Yodh, B. B., Prof.	...	Great Eastern Hotel.
Yachell, E. T.	...	Grand Hotel, Chowringhee.

Z

Zachariah, A. (Miss)	...	Women Hostel.

Continued list of Sessional Members with their local addresses.

Bose, Jagat Kishore	...	C/o S. C. Mukherjee, Esq., I.C.S., 9, Lower Rawdon Street
Ghosh, B. N.	...	24, Santi Ghose Street.

Indian Science Congress
Silver Jubilee

TWENTY-FIFTH SESSION, 1938

CALCUTTA

EXCURSIONS

INFORMATION

1. Members desirous of joining any of the excursions are requested to obtain their tickets on the previous day.

2. The tickets for the excursions have been priced -/4/- or -/8/- annas according to the distance of the route.

3. If less than 20 tickets are sold for any excursion the same may be abandoned and ticket-value refunded on return of the ticket to the office.

4. Tickets will be issued from the office during 10 a.m. to 3 p.m., on presentation of the Membership Cards.

5. In case of limited accommodation, members from outside Bengal will have first preference.

N. B. ALL EXCURSION PARTIES WILL LEAVE BAKER LABORATORIES EVERY DAY AT TIME SPECIFIED AGAINST EACH ROUTE.

INDIAN SCIENCE CONGRESS
SILVER JUBILEE

TWENTY-FIFTH SESSION, 1938
CALCUTTA

Excursion Programme

4th JANUARY, TUESDAY
1-30 P.M.

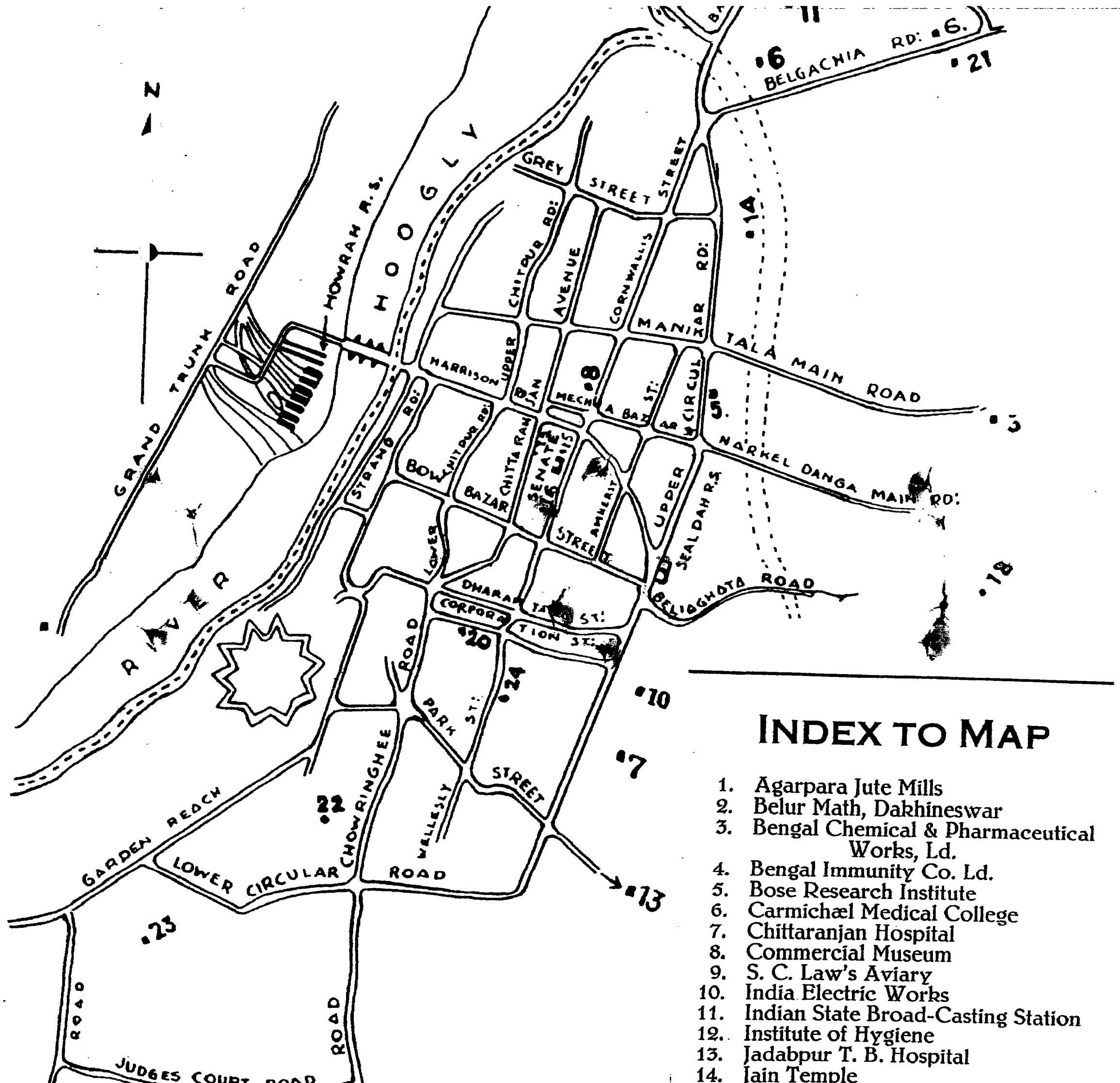
ROUTE		CHARGES
A.	Zoological Garden	As. 8

6th JANUARY, THURSDAY
9 A.M.

A.	Indian Society of Oriental Arts	As. 4
B.	Zoological Garden	As. 8
	Victoria Memorial	
C.	Jain Temple	As. 8
	Dakhineswar, Belur Math	

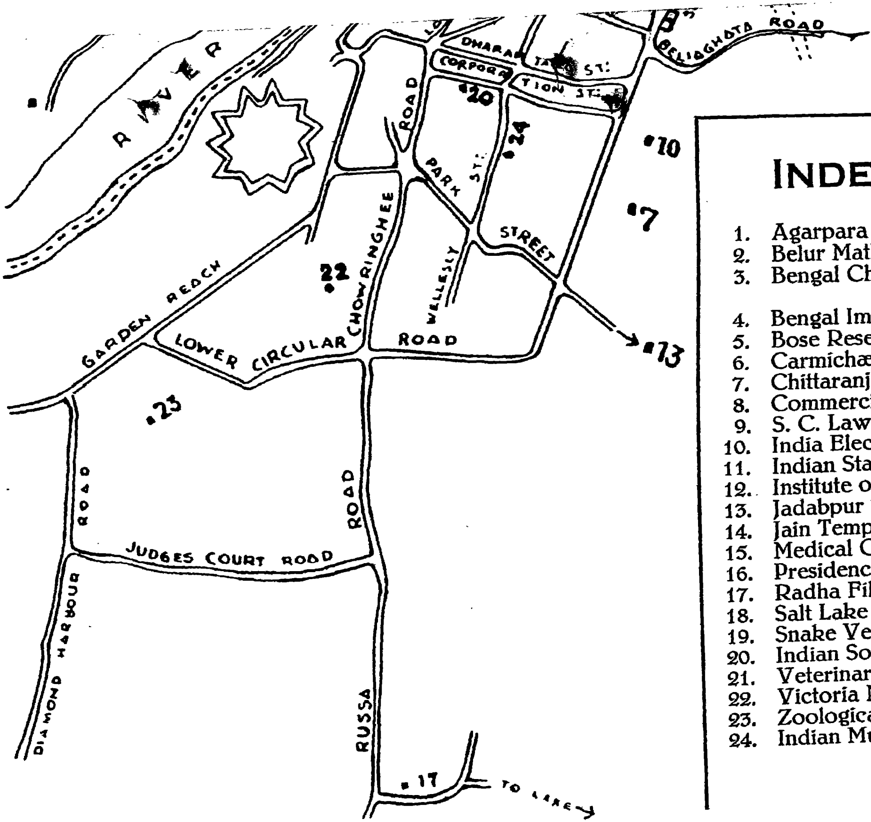
2 P.M.

D.	Carmichæl Medical College	As. 8
	Snake Venom Laboratory	
E.	Radha Film Co.	As. 8
	India Electric Works	
	Lake	
F.	Indian State Broad-Casting Station	As. 8
	Agarpara Jute Mills	



INDEX TO MAP

1. Agarpara Jute Mills
2. Belur Math, Dakhineswar
3. Bengal Chemical & Pharmaceutical Works, Ld.
4. Bengal Immunity Co. Ld.
5. Bose Research Institute
6. Carmichæl Medical College
7. Chittaranjan Hospital
8. Commercial Museum
9. S. C. Law's Aviary
10. India Electric Works
11. Indian State Broad-Casting Station
12. Institute of Hygiene
13. Jadabpur T. B. Hospital
14. Jain Temple



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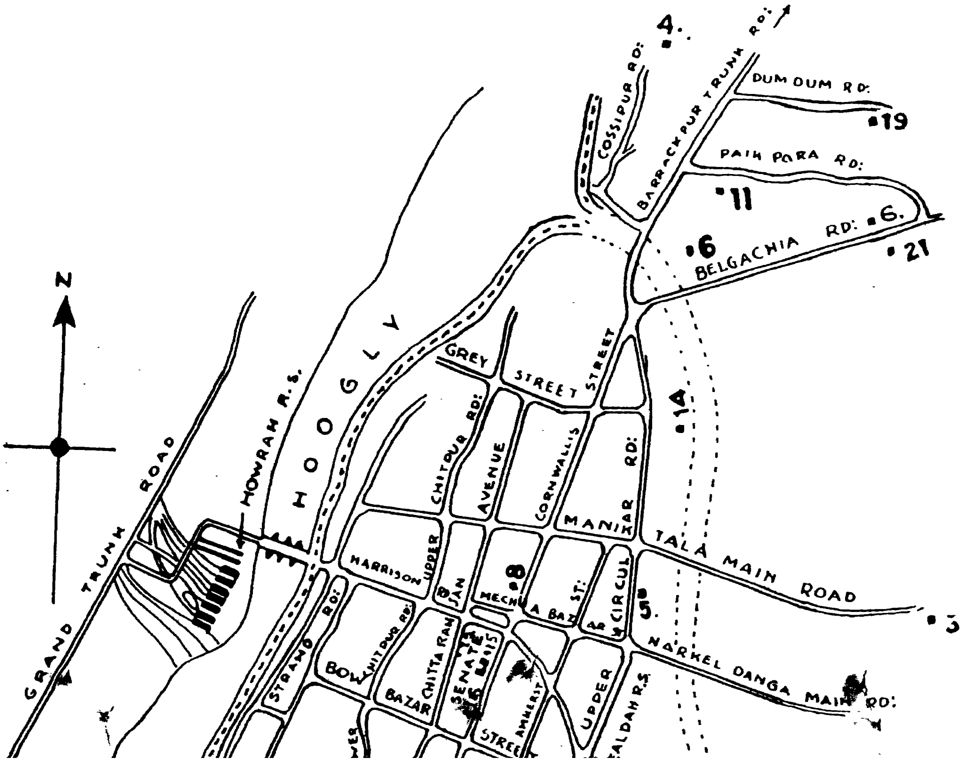
11. Indian State Broad-Casting Station
12. Institute of Hygiene
13. Jadabpur T. B. Hospital
14. Jain Temple
15. Medical College
16. Presidency College
17. Radha Film Co.
18. Salt Lake
19. Snake Venom Laboratory
20. Indian Society of Oriental Arts
21. Veterinary College
22. Victoria Memorial
23. Zoological Garden
24. Indian Museum

1.2.9


N
GRAND TRUNK ROAD
HOWRAH R.S.
HOOGLY
STRAND RD:
BOW
CHITPUR RD:
HARRISON
UPPER CHITPUR RD:
BAZAR
CHITTA RANJAN AVENUE
SENATE
GREY STREET
STREET
8
AMHERST
MECHUA BAZ ST:
CORNWALLIS STREET
UPPER
CIRCUL
MANI
KAR RD:
ALDAH R.S.
5
14
TALA MAIN ROAD
NARKEL DANGA MAIN RD:
3
COSSIPUR RD:
4
BARRACKPUR TRUNK RD:
DUM DUM RD:
19
PAIK PARA RD:
11
6
BELGACHIA RD:
21

INDIAN SCIENCE CONGRESS
SILVER JUBILEE

TWENTY-FIFTH SESSION, 1938
CALCUTTA

Excursion Programme

7th JANUARY, FRIDAY

1-30 P.M.

ROUTE		CHARGES
A.	Indian Museum	As. 4
B.	Veterinary College	As. 4
C.	Salt Lake	As. 8

9th JANUARY, SUNDAY

1-30 P.M.

A.	Bose Research Institute S. C. Law's Aviary	As. 8
B.	Chittaranjan Hospital Jadabpur T. B. Hospital	As. 8

Medical College, Presidency College Physiology Department, Commercial Museum & other Institutions.

5th January, Wednesday
8 A.M. to 10 A.M.
MEDICAL COLLEGE HOSPITALS

1-30 P.M. to 4 P.M.
ALL INDIA INSTITUTE OF HYGIENE AND PUBLIC HEALTH

8th January, Saturday
6 P.M.
COMMERCIAL MUSEUM

9th January, Sunday
1-30 P.M. to 4 P.M.
PRESIDENCY COLLEGE PHYSIOLOGY DEPT.

Other Entertainments

3rd JANUARY, MONDAY
2 P.M. to 5-30 P.M.
Local Reception Committee 'At Home' on board the Steamer

4th JANUARY, TUESDAY
5 P.M.
Civic Reception by the Corporation of Calcutta at Town Hall
10 P.M.
Bratachari Demonstration at Senate House

5th JANUARY, WEDNESDAY
4-30 P.M. to 6 P.M.
Bengal Chemical & Pharmaceutical Works Ld., 'At Home', at their Manicktola Factory, 164, Manicktola Main Road
Conveyance arranged by the host, will leave Baker Laboratories at 3 P.M.

7th JANUARY, FRIDAY
4 P.M.
Afternoon Party at Government House
9-30 P.M.
Musical Soiree
arranged by the Local Reception Committee at First Empire Theatre

8th JANUARY, SATURDAY
5 P.M.
Afternoon Party by the Bengal Immunity Co., Ltd.
Conveyance arranged by the host will leave Baker Laboratories at 4 P.M.
8-30 P.M.
Congress Dinner

9th JANUARY, SUNDAY
4-30 P.M. to 6-30 P.M.
Farewell party by the University of Calcutta

Bengal Autotype Co., Calcutta.

Indian Science Congress Association

TWENTY-FIFTH (SILVER JUBILEE) SESSION,

HELD JOINTLY WITH THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

January 3rd, 4th, 5th, 6th, 7th, 8th and 9th, 1938

to be held at the

Senate House, Calcutta University, the Baker Laboratories of the Presidency College, the University Buildings, the Calcutta Medical College, and the All-India Institute of Hygiene and Public Health, Calcutta.

PROGRAMME.

(Provisional.)

CALCUTTA

Royal Asiatic Society of Bengal, 1, Park Street.

IMPORTANT NOTICE.

This programme is only provisional. A revised and detailed programme including the list of local excursions, social functions, and entertainments will be issued to members on Sunday, 2nd January, 1938, from the Local Secretaries' office.

The abstracts of papers to be read at the *Discussions* will be issued at the same time.

NOTE REGARDING INVITATIONS TO FOREIGN SCIENTISTS.

(1) British Scientists

The list of British scientists drawn up by the Executive Committee before the Hyderabad Session was duly sent to the British Association. In addition, the names of those British scientists which were suggested at the meeting of the Council and of the General Committee were also sent. Invitations were sent by the British Association to all these scientists. Unfortunately, quite an appreciable number of them were unable to accept the invitation to attend the Jubilee Session. Even amongst those who intimated that they hoped to come, a considerable number have not ultimately found it possible to do so. Amongst the latter mention may be made of the following :

1. Prof. G. Barger, F.R.S., Professor of Chemistry, University of Edinburgh.
2. Prof. F. G. Donnan, C.B.E., F.R.S., Professor of Chemistry, University College, London.
3. Dr. E. Griffiths, F.R.S., Principal Scientific Officer, National Physical Laboratory, Teddington.
4. Sir Arthur Harden, F.R.S., Nobel Laureate, Late Head of Biochemical Department, Lister Institute of Preventive Medicine, London.
5. Dr. G. W. C. Kaye, Superintendent, Physics Department, National Physical Laboratory, Teddington.
6. Sir Guy A. K. Marshall, C.M.G., F.R.S., Director, Imperial Institute of Entomology, London.
7. Sir Gilbert T. Morgan, F.R.S., Director, Chemical Research Laboratory, Teddington.
8. Miss E. R. Saunders, Lately Lecturer in Botany, Newnham College, Cambridge.
9. Prof. G. P. Thomson, F.R.S., Nobel Laureate, Professor of Physics, Imperial College of Science and Technology, London.
10. Prof. V. Gordon Childe, Professor of Prehistoric Archæology, University of Edinburgh.

(2) Non-British Scientists

Invitations were issued to more than 130 non-British scientists in accordance with the suggestions received. Unfortunately, with one exception, none were able to accept. In addition, invitations, offering a subvention of £100, were sent

to a specially selected number, while in certain cases an additional subvention of about £50 was offered by other Institutions (Dacca University and the Indian Association for the Cultivation of Science). In spite of this quite a number were unable to accept the invitation. The reason given in the majority of cases was the difficulty of getting away from their work in December and January, and of arranging for it during their absence; other reasons were: (*a*) previous engagements, (*b*) illness, (*c*) unavoidable circumstances. The following were unable to accept our invitation:

1. Dr. I. Langmuir, Nobel Laureate, Research Laboratory of the General Electric Company, New York, U.S.A.
2. Prof. The Svedberg, Nobel Laureate, University of Upsala, Sweden.
3. Prof. Jean Perrin, Nobel Laureate, Director, Institut de Chimie Physique, Sorbonne, Paris, France.
4. Prof. Otto von Warburg, Nobel Laureate, Kaiser-Wilhelm Institute fur Zell-Biologie, Berlin.

†5. Prof. G. von Hevesy, Nobel Laureate, Institute of Theoretical Physics, Carlsberg Laboratory, Copenhagen, Denmark.

*6. Prof. N. Bohr, Nobel Laureate, Institute of Theoretical Physics, Carlsberg Laboratory, Copenhagen, Denmark.

7. Prof. R. A. Millikan, Norman Bridge Laboratory, Pasadena, California, U.S.A.

8. Prof. M. Siegbahn, Physikalische Institut, The University, Upsala, Sweden.

9. Prof. M. von Laue, Kaiser-Wilhelm Institute for Physics, Berlin-Dahlem, Germany.

10. Professors Mr. and Mrs. Joliot-Curie, Institute du Radium, Paris.

*11. Prof. L. Diels, General Director, Botanical Gardens and Museum, Berlin.

*12. Prof. Dr. L. Aschoff, Freiburg, Germany.

†13. Prof. B. B. Polynov, Institut fur Bodenkunde, Akademie der Wissenschaft, Moscow, U.S.S.R. (Russia).

†14. Prof. N. I. Vavilov, Director of the Staats-Institute for Experimental Agronomy, Leningrad, U.S.S.R. (Russia).

15. Prof. G. T. Morgan, Nobel Laureate, University of California, U.S.A.

16. Prof. U. Mc. Dougall, Duke University, Durham, U.S.A.

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* Accepted and then intimated inability to come on account of unavoidable circumstances.

† No reply has yet been received.

Indian Science Congress Association

PROGRAMME

(Provisional)

TWENTY-FIFTH ANNUAL MEETING

January 3rd, 4th, 5th, 6th, 7th, 8th and 9th, 1938

to be held at the

Senate House, Calcutta University, the Baker Laboratories of the Presidency College, the University Buildings, the Calcutta Medical College, and the All-India Institute of Hygiene and Public Health, Calcutta.

Patrons

HIS EXCELLENCY THE MOST HONOURABLE LORD VICTOR ALEXANDER JOHN HOPE, P.C., KT., G.M.S.I., G.M.I.E., O.B.E., D.L., T.D., THE MARQUESS OF LINLITHGOW, VICEROY AND GOVERNOR GENERAL OF INDIA.

HIS EXCELLENCY THE RT. HON. SIR JOHN ANDERSON, P.C., G.C.B., G.C.I.E., GOVERNOR OF BENGAL.

Vice-Patrons

THE HON. KUNWAR SIR JAGDISH PRASAD, K.C.S.I., C.I.E., O.B.E., MEMBER IN CHARGE, DEPARTMENT OF EDUCATION, HEALTH AND LANDS, VICEROY'S EXECUTIVE COUNCIL.

THE RT. HON. SIR AKBAR HYDARI, P.C., LL.D., PRESIDENT, H.E.H. THE NIZAM'S EXECUTIVE COUNCIL.

President

SIR JAMES JEANS, D.SC., SC.D., LL.D., F.I.C., F.R.S.

Presidents of Sections

1.	*Mathematics and Physics.*	Dr. C. W. B. Normand, M.A., D.Sc., F.N.I., Director-General of Observatories, Meteorological Office, Poona 5.
2.	*Chemistry* ..	Prof. S. S. Bhatnagar, O.B.E., D.Sc., F.Inst.P., F.N.I., Director, University Chemical Laboratories, Lahore.
3.	*Geology* ..	D. N. Wadia, Esq., M.A., F.G.S., F.R.G.S., F.N.I., F.R.A.S.B., Geologist, Geological Survey of India, 27, Chowringhee, Calcutta.
4.	*Geography and Geodesy.*	Dr. A. M. Heron D.Sc., F.R.G.S., F.R.S.E., F.N.I., F.R.A.S.B., Director, Geological Survey of India, 27, Chowringhee, Calcutta.
5.	*Botany* ..	Prof. B. Sahni, Sc.D., F.R.S., Professor of Botany, Lucknow University, Lucknow.
6.	*Zoology* ..	Prof. G. Matthai, M.A., Sc.D., F.L.S., F.R.S.E., F.N.I., I.E.S., Professor of Zoology, Government College, Lahore.
7.	*Entomology* ..	Mohamad Afzal Husain, Esq., M.A., M.Sc., F.N.I., I.A.S., Principal, Punjab Agricultural College, Lyallpur, Punjab.
8.	*Anthropology* ..	Dr. B. S. Guha, M.A., Ph.D., F.N.I., Zoological Survey of India, Indian Museum, Calcutta.
9.	*Agriculture* ..	Rao Bahadur T. S. Venkatraman, C.I.E., B.A., I.A.S., F.N.I., Imperial Sugarcane Expert, Lawley Road, Coimbatore.
10.	*Medical Research*	Sir U. N. Brahmachari, M.A., M.D., Ph.D., F.N.I., F.R.A.S.B., Professor of Tropical Medicine,, Carmichael ·Medical College; Honorary Professor of Biochemistry, University of Calcutta; 82/3, Cornwallis Street, Calcutta.
11.	*Veterinary Research.*	Col. Sir Arthur Olver, C.B., C.M.G., F.R.C.V.S., F.N.I., Animal Husbandry Expert, Imperial Council of Agricultural Research, New Delhi.

12. *Physiology* .. Bt.-Col. R. N. Chopra, C.I.E., M.A., M.D., Sc.D., M.R.C.P., K.H.P., F.N.I., F.R.A.S.B., I.M.S., Offg. Director and Professor of Pharmacology, School of Tropical Medicine, Chittaranjan Avenue, Calcutta.

13. *Psychology* .. Dr. G. Bose, M.B., D.Sc., F.N.I., University College of Science, 92, Upper Circular Road, Calcutta.

Recorders of Sections

1. *Mathematics and Physics.* Prof. N. R. Sen, D.Sc., Ph.D., F.N.I., University College of Science, 92, Upper Circular Road, Calcutta.

2. *Chemistry* .. Dr. Habib Hassan, L.Ag., M.Sc., Ph.D., Government Industrial Laboratory, Hyderabad, Deccan.

3. *Geology* .. Prof. L. Rama Rao, M.A., F.G.S., Professor of Geology, Central College, Bangalore.

4. *Geography and Geodesy.* N. Subramanyam, Esq., M.A., L.T., F.R.G.S., Lecturer in Geography, Teachers College, Saidapet, Madras.

5. *Botany* .. Prof. M. Sayeed-ud-Din, M.A., B.Sc., F.R.M.S., Professor and Head of the Botany Department, Osmania University College, Hyderabad, Deccan.

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7. *Entomology* .. Dr. H. S. Pruthi, M.Sc., Ph.D., F.N.I., Imperial Entomologist, Imperial Institute of Agricultural Research, New Delhi.

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General Arrangements

The Congress Session will be held in the Presidency College, the University Buildings, the Calcutta Medical College and the All-India Institute of Hygiene and Public Health, Calcutta.

The Office of the Local Secretaries will be opened in the Presidency College, Baker Laboratories, on December 23rd, 1937.

The Office of the General Secretaries will be opened in the Baker Laboratories on January 2nd, 1938.

The Information Bureau is located in a room on the ground floor of the Baker Laboratories, Presidency College, Calcutta.

The Reception Room is located in the Science Library on the first floor of the Baker Laboratories. Stationery and writing materials for the use of members will be available there. A number of the local daily papers will be provided in this room.

A Post and Telegraph Office will be opened in the Presidency College from December 23rd, 1937. Members may address their letters C/o Indian Science Congress, Calcutta. All communications to the Local Secretaries may also be sent to this address from December 3rd, 1937.

A telephone connection will be available for the use of members near the Local Secretaries' office.

A restaurant, where refreshments will be available, will be opened from January 2nd, 1938.

Details of the *whole-day Excursions* will be announced in the revised programme to be issued on January 2nd, 1938.

An interesting programme of *visits to institutions* of educational, scientific, technical, and industrial interest is being arranged, details of which will be included in the revised programme.

A *Science Congress Handbook* (Calcutta, 1938) and a *List of Members* with their local addresses, where known, together with *Invitation Cards to social functions*, will be issued to members from the Local Secretary's office between 12 noon and 6 P.M. on January 2nd, 1938, and between 8 A.M. and 9 A.M. on January 3rd.

Members are requested to produce their membership cards when applying for these.

Opening Proceedings and the General Presidential Address.—The Congress will be opened by His Excellency the Viceroy in the Senate House of the Calcutta University at 10 A.M. on Monday, January 3rd, 1938. The address of the General President will begin immediately afterwards. **Members must be in their seats before 9-30 a.m.**

The Evening Popular Lectures will be delivered in the Senate House, Calcutta University, as follows :—

MONDAY, JANUARY 3RD, 1938, AT 6-30 P.M.

'Stages in the Growth of Civilization', by Prof. H. J. Fleure, F.R.S., Professor of Geography in the University of Manchester.

TUESDAY, JANUARY 4TH, 1938, AT 7 P.M.

'Isotopes' by Dr. F. W. Aston, Sc.D., LL.D., F.R.S., Nobel Laureate, Cavendish Laboratory, Cambridge.

WEDNESDAY, JANUARY 5TH, 1938, at 6-30 P.M.

By Sir James Jeans, D.Sc., Sc.D., LL.D., F.R.S.

FRIDAY, JANUARY 7TH, 1938, AT 6-30 P.M.

'The Milky Way and Beyond', by Prof. Sir Arthur Eddington, D.Sc., LL.D., F.R.S., Plumian Professor of Astronomy in the University of Cambridge.

SATURDAY, JANUARY 8TH, 1938, AT 6-30 P.M.

'The Biology of Death' by Prof. F. A. E. Crew, M.D., D.Sc., Ph.D., Professor and Director of the Institute of Animal Genetics in the University of Edinburgh.

DAILY PROGRAMME

(Provisional)

MONDAY, JANUARY 3RD, 1938.

10 A.M. ..	H.E. the Viceroy opens the Session.
	General President's Address.
12 NOON ..	Meetings of the Sectional Committees.
2 P.M. TO 5-30 P.M.	River Trip on the Hoogly. The Local Reception Committee will be 'At Home' on board the steamer.
6-30 P.M. ..	Popular Lecture on 'Stages in the Growth of Civilization' by Prof. H. J. Fleure, F.R.S., Professor of Geography in the University of Manchester.
7-45 P.M. ..	Meeting of the Council.
8-30 P.M. ..	Cambridge University Dinner.

TUESDAY, JANUARY 4TH, 1938.

9 A.M. to 9-30 A.M. ..	Meetings of the Sectional Committees.
9-30 A.M. to 12-30 P.M.	Meetings of Sections.
9-30 A.M. ..	Presidential Address: Section of Botany: 'Palæobotany in India, a retrospect'.
10-30 A.M. ..	Presidential Address: Section of Physiology: 'The physiology of the individual in the tropics'.
11-30 A.M. ..	Presidential Address: Section of Agriculture: 'Hybridization in and with the genus *Saccharum* (its scientific and economic aspects)'.
10-30 A.M. to 12 NOON	Discussion on 'Animal ecology in relation to India'. (SECTION OF ZOOLOGY).
12-30 P.M. ..	Luncheon by the Indian Society of Soil Science to Soil Science delegates at the Great Eastern Hotel.
1-30 P.M. to 3 P.M. ..	(1) Discussion on 'Blood groupings and racial classification'. (SECTION OF ANTHROPOLOGY.)
	(2) Discussion on 'Biological control of insect pests'. (SECTIONS OF ENTOMOLOGY AND AGRICULTURE.)
	(3) Discussion on 'Discrepancies between the chronological testimony of fossil plants and animals'. (SECTIONS OF GEOLOGY AND BOTANY).
1-30 P.M. to 4 P.M. ..	(1) Discussion on 'Recent advances in molecular structure from the physico-chemical standpoint'. (SECTIONS OF MATHEMATICS AND PHYSICS AND CHEMISTRY). Held in co-operation with the Indian Physical Society.
	(2) Discussion on 'Animals and their diseases in relation to man'. (SECTIONS OF MEDICAL RESEARCH, VETERINARY RESEARCH, AND PHYSIOLOGY.)

	(3) Discussion on 'The absorption of salts by plants'. (SECTIONS OF BOTANY AND CHEMISTRY). Held in co-operation with the Society of Biological Chemists, India.
	(4) Zoology Sectional Excursion to Dr. S. C. Law's aviary and to the Indian Museum.
	(5) Geography Sectional Excursion: air trip over Calcutta.
3 P.M. TO 4 P.M. ..	(1) Annual Meeting of the Society of Biological Chemists, India.
	(2) Annual Meeting of the Indian Anthropological Institute.
	(3) Annual Meeting of the Indian Society of Soil Science.
5 P.M.	Civic Reception by the Corporation of Calcutta.
7 P.M.	Popular Lecture on 'Isotopes' by Dr. F. W. Aston, Sc.D., LL.D., F.R.S., Cavendish Laboratory, Cambridge.
10 P.M.	Bratachari Demonstration.

WEDNESDAY, JANUARY 5TH, 1938.

9 A.M. to 9-30 A.M. ..	Meetings of the Sectional Committees.
9-30 A.M. to 12-30 P.M.	Meetings of Sections.
9-30 A.M. ..	(1) Presidential Address: Section of Medical Research: 'The Conquest of Kala-azar and certain observations on the chemiotherapy of Malaria.
	(2) Presidential Address: Section of Psychology: 'Ambivalence'.
10-30 A.M. ..	Presidential Address: Section of Mathematics and Physics: 'The Sources of Energy of Storms'.
11-30 A.M. ..	(1) Presidential Address: Section of Geography and Geodesy: 'The Physiography of Rajputana'.
	(2) Presidential Address: Section of Entomology: 'Entomology in India, past, present and future.'

9-30 A.M. to 11 A.M.	(1) Discussion on 'Algal problems peculiar to the tropics, with special reference to India'. (SECTION OF BOTANY.)
	(2) Discussion on 'The place of systematics and morphology in the study of the living animal'. (SECTION OF ZOOLOGY.)
9-30 A.M. to 11-30 A.M.	Discussion on 'The teaching of geography in India'. (SECTION OF GEOGRAPHY AND GEODESY.)
11 A.M. to 12-30 P.M.	(1) Discussion on 'The significance of boundary faults in the Sub-Himalayas'. (SECTION OF GEOLOGY).
	(2) Discussion on 'Immunity in protozoal infections'. (SECTION OF MEDICAL RESEARCH).
	(3) Discussion on 'Recent advances in the structure of alkaloids'. (SECTION OF CHEMISTRY). Held in co-operation with the Society of Biological Chemists, India.
12-30 P.M. ..	Luncheon by the Indian Chemical Society at the Great Eastern Hotel.
1-30 P.M. to 3 P.M. ..	(1) Meeting of the Executive Committee.
	(2) Discussion on 'The dissemination of cereal rusts in India'. (SECTION OF BOTANY.)
1-30 P.M. to 4 P.M. ..	(1) Discussion on 'The relation of Zoology to Medicine, Veterinary Science and Agriculture'. (SECTIONS OF ZOOLOGY, MEDICAL RESEARCH, VETERINARY RESEARCH, ENTOMOLOGY AND AGRICULTURE.)
	(2) Discussion on 'The importance of Anthropological studies for India'. (SECTION OF ANTHROPOLOGY.)
	(3) Geography Sectional Excursion to the Salt Lakes.

1-30 P.M. to 2-30 P.M.	(1) Annual Meeting of the Physiological Society of India. (2) Annual Meeting of the Institute of Chemistry of Great Britain and Ireland (Indian Section).
3 P.M. to 4 P.M. ..	(1) Annual Meeting of the Indian Chemical Society. (2) Annual Meeting of the Indian Physical Society.
2-30 P.M. to 4 P.M. ..	(1) Medical Sectional Excursion to the All-India Institute of Hygiene and Public Health, the Calcutta School of Tropical Medicine, and the Calcutta Medical College. (2) Physiology Sectional Excursion to the All-India Institute of Hygiene and Public Health, the Calcutta School of Tropical Medicine, and the Calcutta Medical College.
4 P.M. to 4-30 P.M. ..	Inauguration of the Indian Society of Pathology and Microbiology.
4-30 P.M. to 6-0 P.M.	Afternoon Party by the Bengal Chemical and Pharmaceutical Works at Manicktala.
6-30 P.M. ..	Popular Lecture by Sir James Jeans, D.Sc., Sc.D., LL.D., F.R.S.

THURSDAY, JANUARY 6TH, 1938.	(*a*) Whole day excursions. (1) Excursions to Tatanagar, Ranchi (Indian Lac Research Institute), Bolepur, Murshidabad, and Puri (Konarak). Parties will leave Calcutta on the evening of January 5th, and arrive back on the early morning of January 7th. (2) Excursions to Port Canning, (Botany and Zoology Sections), and to a typical jute mill. These excursions will not involve a night's stay away from Calcutta.

(*b*) Half day excursions.

Excursions to the Salt Lakes (Botanists); Botanical Gardens; visit to a film studio; visit to the Calcutta Broadcasting Station; visit to the India Electric Works, Ltd., and other places.

FRIDAY, JANUARY 7TH, 1938.

9-30 A.M. to 12-30 P.M.	Meetings of Sections.
9-30 A.M. ..	Presidential Address: Section of Zoology: 'Zoology and its advancement in India'.
10-30 A.M. ..	Presidential Address: Section of Veterinary Research: 'Development of Veterinary Work in India.'
11-30 A.M. ..	Presidential Address: Section of Chemistry: 'A survey of recent advances in magnetism relating to Chemistry'.
9-30 A.M. to 12-30 P.M.	Discussion on 'Contributions of abnormal psychology to normal psychology'. (SECTION OF PSYCHOLOGY.)
10-30 A.M. TO 11-30 A.M.	Discussion on 'Physiology of the individual in health and disease.' (SECTION OF PHYSIOLOGY.)
11 A.M. TO 12-30 P.M.	(1) Discussion on 'The origin of banded gneisses'. (SECTION OF GEOLOGY.)
	(2) Discussion on 'The position of Entomology in the Indian Universities'. (SECTIONS OF ZOOLOGY AND ENTOMOLOGY.)
11-30 A.M. TO 12-30 P.M.	Discussion on 'Diet and adaptation to climate'. (SECTION OF PHYSIOLOGY). Held in co-operation with the Society of Biological Chemists, India.
12-30 P.M. ..	(1) Luncheon by the Department of Psychology and its ex-students to the members of the Psychology Section, at the Psychology Laboratory, University College of Science.

	(2) Luncheon by the Botanical Society of Bengal, and the Botany Department, Calcutta University, at 35, Ballygunge Circular Road.
1-30 P.M. to 4 P.M. ..	(1) Discussion on 'Theoretical statistics'. (SECTION OF MATHEMATICS AND PHYSICS). Held in co-operation with the Indian Statistical Conference.
	(2) Discussion on 'Colloids in biology, medicine, and agriculture'. (SECTIONS OF CHEMISTRY, ZOOLOGY, MEDICAL RESEARCH, PHYSIOLOGY, AND AGRICULTURE). Held in co-operation with the Society of Biological Chemists, India.
	(3) Discussion on 'Opportunities for Archæological excavations in India. (SECTION OF ANTHROPOLOGY.)
	(4) Geology Sectional Excursion to the Geological Survey Office, and to the Rock, Mineral, and Fossil galleries in the Indian Museum.
	(5) Entomology Sectional Excursion to the Salt Lakes.
1-30 P.M. to 3 P.M. ..	Psychology Sectional Excursion to the Psychology Laboratory.
2 P.M. to 3 P.M. ..	Conversazione at the Botany Laboratory, Calcutta University, 35, Ballygunge Circular Road.
3 P.M. to 4 P.M. ..	(1) Annual Meeting of the Indian Psychological Association.
	(2) Annual Meeting of the Indian Botanical Society.
4 P.M. ..	Afternoon Party at Government House.
6-30 P.M. ..	Popular Lecture on 'The Milky Way and Beyond' by Prof. Sir Arthur Eddington, D.Sc., LL.D., F.R.S., Plumian Professor of Astronomy in the University of Cambridge.
9-30 P.M. ..	Musical Soiree.

Saturday, January 8th, 1938.

9 a.m. to 9-30 a.m. ..	Meetings of the Sectional Committees.
9-30 a.m. to 12-30 p.m.	Meetings of Sections.
9-30 a.m. ..	Lecture by the Rt. Hon. Lord Samuel, P.C., G.C.B., on 'Science as a basis for philosophy'.
10-30 a.m. ..	Presidential Address: Section of Geology: 'The Structure of the Himalayas and of the North Indian Foreland'.
11-30 a.m. ..	Presidential Address: Section of Anthropology: 'The Racial Composition of the Hindu Kush Tribes'.
9-30 a.m. to 11 a.m.	Discussion on 'A national herbarium for India'. (Section of Botany.) Held in co-operation with the Indian Botanical Society.
11 a.m. to 12-30 p.m.	(1) Discussion on 'Chemistry and industrial development in India'. (Section of Chemistry.) Held in co-operation with the Society of Biological Chemists, India.
	(2) Discussion on 'Nutritional diseases in India'. (Section of Medical Research.) Held in co-operation with the Society of Biological Chemists, India.
	(3) Discussion on 'The application of statistics in agriculture'. (Section of Agriculture.) Held in co-operation with the Indian Statistical Conference.
12-30 p.m. ..	Luncheon by the Geological, Mining and Metallurgical Society of India, at the Great Eastern Hotel.
1-30 p.m. ..	Group Photograph.
2 p.m. to 3-30 p.m. ..	Meeting of the General Committee.
3-30 p.m. to 4-30 p.m.	Annual Meeting of the National Institute of Sciences of India.
5 p.m. ..	Afternoon Party by the Bengal Immunity Co.

6-30 P.M. ..	Popular Lecture on 'The Biology of Death', by Prof. F. A. E. Crew, M.D., D.Sc., Ph.D., Professor and Director of the Institute of Animal Genetics in the University of Edinburgh.
8-15 P.M. for 8-30 P.M.	Congress Dinner.

SUNDAY, JANUARY 9TH, 1938.

9 A.M. to 9-30 A.M. ..	Meetings of the Sectional Committees.
9-30 A.M. to 12-30 P.M.	Sectional Meetings.
10-30 A.M. ..	Discussion on 'The practicable possibility of breeding immune strains'. (SECTION OF VETERINARY RESEARCH.)
11-30 A.M. to 12-30 P.M.	Discussion on 'Pre-Cambrian Sedimentation'. (SECTION OF GEOLOGY.)
1-30 P.M. to 2-30 P.M.	Annual Meeting of the Institution of Chemists (India).
1-30 P.M. to 4 P.M. ..	(1) Discussion on 'River Physics in India'. (SECTIONS OF MATHEMATICS AND PHYSICS, GEOLOGY, GEOGRAPHY AND GEODESY, AND AGRICULTURE.) Held in co-operation with the National Institute of Sciences of India, and the Indian Physical Society.
	(2) Discussion on 'The species concept in the light of cytology and genetics'. (SECTIONS OF BOTANY, ZOOLOGY AND AGRICULTURE.)
	(3) Medical Sectional Excursion to the Carmichael Medical College, the Chittaranjan Seva Sadan, and the Jadabpur Tuberculosis Hospital.
	(4) Physiology Sectional Excursion to the Bose Institute, the Carmichael Medical College, and Dr. S. C. Law's Aviary.
	(5) Veterinary Sectional Excursion to the Bengal Veterinary College, Belgachia.
4-30 P.M. to 6-30 P.M.	Farewell Party by the University of Calcutta.

ANNOUNCEMENTS.

1. The Annual Meeting of the National Institute of Sciences of India will be held at 3-30 P.M. on Saturday, January 8, 1938. All members of the Congress are invited to attend.

2. The Annual Meeting of the Indian Chemical Society will be held at 3 P.M. on Wednesday, January 5, 1938.

3. The Annual Meeting of the Indian Physical Society will be held at 3 P.M. on Wednesday, January 5, 1938.

4. The Annual Meeting of the Institute of Chemistry of Great Britain and Ireland (Indian Section) will be held at 1-30 P.M. on Wednesday, January 5, 1938.

5. The Annual Meeting of the Indian Botanical Society will be held at 3 P.M. on Friday, January 7, 1938.

6. The Annual Meeting of the Society of Biological Chemists, India, will be held at 3 P.M. on Tuesday, January 4, 1938.

7. The Annual Meeting of the Indian Psychological Association will be held at 3 P.M. on Friday, January 7, 1938.

8. The Annual Meeting of the Indian Society of Soil Science will be held at 3 P.M. on Tuesday, January 4, 1938.

9. The Annual Meeting of the Physiological Society of India will be held at 1-30 P.M. on Wednesday, January 5, 1938.

10. The Annual Meeting of the Indian Anthropological Institute will be held at 3 P.M. on Tuesday, January 4, 1938.

11. The Annual Meeting of the Institution of Chemists (India) will be held at 1-30 P.M. on Sunday, January 9, 1938.

LIST OF BRITISH ASSOCIATION DELEGATES AND OTHERS SPECIALLY INVITED.

I = Taking the pre-Congress Tour.

II = Taking the post-Congress Tour.

Ashworth, Mrs. J. H., Hillbank, Grange Loan, Edinburgh. I, II.

Aston, Dr. F. W., Sc.D., D.Sc., LL.D., F.R.S., Fellow of Trinity College, Cambridge. I, II.

Aston, Miss, Trinity College, Cambridge. I, II.

Baily, Prof. F. G., Emeritus Professor of Electrical Engineering, Heriot-Watt College, Edinburgh. Newbury, Juniper Green, Midlothian. I.

Baily, Mrs. F. G., Newbury, Juniper Green, Midlothian. I.

Baily, Harold, M.B.E., 74, Lawn Rd., London, N.W. 3. I.

Baily, Mrs. H., 74, Lawn Rd., London, N.W. 3. I.

Baly, Prof. E. C. C., C.B.E., F.R.S., Professor of Inorganic Chemistry in the University of Liverpool. Rocklands, Allerton Road, Mossley Hill, Liverpool. I, II.

Baly, Mrs., Rocklands, Allerton Rd., Mossley Hill, Liverpool. I, II.

Barker, Prof. Ernest, Litt.D., D.Litt., LL.D., Professor of Political Science in the University of Cambridge. 17, Cranmer Road, Cambridge. I, II.

Beaufort, Prof. L. F. de, Director of the Zoological Museum, Amsterdam. I, II.

Beaufort, Mme. de, Zoological Museum, Amsterdam. I, II.

Bishop, Mrs. E., 1, Summerhill Terrace, Berwick-upon-Tweed. I, II.

Blackman, Prof. V. H., Sc.D., F.R.S., Professor of Plant Physiology and Director of the Biological Laboratories, Imperial College of Science and Technology, London, S.W. 7. 17, Berkeley Place, London, S.W. 19. I.

Blackman, Miss, 17, Berkeley Place, London, S.W. 19. I.

Boswell, Prof. P. G. H., O.B.E., D.Sc., F.R.S., Professor of Geology, Imperial College of Science and Technology, London, S.W. 7. General Treasurer of the British Association. I, II.

Buller, Prof. A. H. Reginald, Ph.D., D.Sc., LL.D., F.R.S., lately Professor of Botany in the University of Manitoba. The Herbarium, Kew, Surrey. I, II.

Buxton, Prof. P. A., Professor of Medical Entomology, University of London ; Director of the Department of Entomology, London School of Hygiene and Tropical Medicine. Grit Howe, Gerrards Cross, Bucks. I, going as far as Madras.

Buxton, Mrs., Grit Howe, Gerrards Cross, Bucks. I, II.

Caie, J. M., B.Sc., Assistant Secretary in the Department of Agriculture for Scotland. 2 Cobden Rd., Edinburgh. I, (? II).

Carpenter, Prof. G. D. Hale, M.B.E., D.M., M.R.C.S., L.R.C.P., Hope Professor of Zoology (Entomology) in the University of Oxford. I, II.

Carpenter, Mrs. Hale, Penguelle, Hid's Copse Road, Cumnor Hill, Oxford. I, II.

Cipriani, Prof. L., Director of the National Museum of Anthropology and Ethnology, Royal University, Florence, Italy. I, II.

Comber, Prof. N. M., D.Sc., Professor of Agricultural Chemistry in the University of Leeds.

Coxhead, Miss, Chemical Laboratories, Brownlow St., Liverpool.

Crew, Prof. F. A. E., M.D., D.Sc., Ph.D., Professor and Director of the Institute of Animal Genetics in the University of Edinburgh. Institute of Animal Genetics, West Mains Rd., Edinburgh. I, II.

Crowther, E. M., D.Sc., Head of the Chemistry Department, Rothamsted Experimental Station, Harpenden, Herts. I.

Cullis, Prof. Winifred, C.B.E., D.Sc., LL.D., Sophia Jex-Blake Professor of Physiology, University of London, London (Royal Free Hospital) School of Medicine for Women. 8, St. Martin's Place, London, W.C. 2. I, (? II).

Darlington, C. D., Ph.D., D.Sc., Cytologist in the John Innes Horticultural Institution, 21, Mostyn Rd., London, S.W. 19. I, (II ?).

Darwin, C. G., Sc.D., F.R.S., Master of Christ's College, Cambridge. I, II.

Darwin, Mrs., Christ's College, Cambridge. I, II.

du Toit, Dr. A. L., Consulting Geologist, P. O. Box 4565, Johannesburg, S. Africa. I, II.

du Toit, Mrs., P.O. Box 4565, Johannesburg, S. Africa. I, II.

Dymond, T. S., 14, Albany Rd., St. Leonards-on-Sea, Sussex. I, II.

Eddington, Prof. Sir A. S., D.Sc., LL.D., F.R.S., Plumian Professor of Astronomy and Experimental Philosophy in the University of Cambridge. The Observatory, Cambridge. I, II.

Eickstedt, Prof. F. von, Director of the Anthropological Institute, Breslau.

Fawcett, Prof. C. B., D.Sc., Professor of Economic and Regional Geography in the University of London. 17, Middleway, London, N.W. 11. I, II.

Fearnsides, Prof. W. G., F.R.S., Sorby Professor of Geology in the University of Sheffield. 11, Ranmoor Crescent, Sheffield 10. I (from Delhi).

Fermor, Sir Lewis L., O.B.E., D.Sc., F.R.S., formerly Director of the Geological Survey of India. C/o Lloyd's Bank, Ltd., 6, Pall Mall, London, S.W. 1. I (to Delhi).

Fermor, Lady, C/o Lloyd's Bank, Ltd., 6, Pall Mall, S.W. 1. I (to Delhi).

Fisher, Prof. R. A., Sc.D., D.Sc., F.R.S., Galton Professor of Eugenics in University College, London. Galton Laboratory, University College, Gower St., W.C. 1. I.

Fleure, Prof. H. J., D.Sc., F.R.S., Professor of Geography in the University of Manchester. 123, Lapwing Lane, Didsbury, Manchester. I, (? II).

Franco, Prof. E. E., (Faculty of Medicine), University of Pisa, Italy.

Fritsch, Prof. F. E., D.Sc., Ph.D., F.R.S., Professor of Botany in the University of London. Pilgrim's End, West Humble, Dorking, Surrey. I.

Fritsch, Mrs., Pilgrim's End, West Humble, Dorking, Surrey. I.

Gates, Prof. R. Ruggles, Ph.D., D.Sc., LL.D., F.R.S., Professor of Botany in the University of London (King's College). 33, Woburn Sq., London, W.C. 1. I.

Gordon, Prof. W. T., D.Sc., University Professor of Geology in the University of London (King's College). King's College, Strand, W.C. 2. I, (? II).

Hallsworth, H. M., C.B.E., Member of the Unemployment Assistance Board (formerly Professor of Economics, Armstrong College, Newcastle-on-Tyne). Chesneys, St. Ives, Hunts. I, II.

Harrison, Prof. J. W. Heslop, D.Sc., F.R.S., Professor of Botany and Reader in Genetics, King's College, Newcastle-upon-Tyne. I, (? II).

Henderson, Sir James B., LL.D., D.Sc., Formerly Professor of Applied Mechanics in the Royal Naval College, Greenwich. 38, Blackheath Park, S.E. 3. I.

Henderson, Lady, 38, Blackheath Park, S.E. 3. I.

Hendrick, Prof. J., B.Sc., Strathcona-Fordyce Professor of Agriculture in the University of Aberdeen. Marischal College, Aberdeen. I, II.

Hill, Sir Arthur, K.C.M.G., Sc.D., D.Sc., F.R.S., Director of the Royal Botanic Gardens, Kew, Surrey. I.

Hobday, Sir Frederick, C.M.G., Formerly Principal and Dean of the Royal Veterinary College, London, 31, Argyll Rd., W. 8. I, II.

Hopwood, Dr. A., Analytical Chemist. 43, Hylton Drive, Cheadle Hulme, Cheshire. I, II.

Hopwood, Mrs., 43, Hylton Drive, Cheadle Hulme, Cheshire. I, II.

Howarth, O. J. R., O.B.E., Ph.D., Secretary of the British Association. I, II.

Howarth, Mrs., Down House, Downe, Kent. I, II.

Howe, Prof. G. W. O., D.Sc., James Watt Professor of Electrical Engineering in the University of Glasgow. Lismore House, Kelvin Drive, Glasgow, N.W. I, II.

Jeans, Sir James H., D.Sc., Sc.D., LL.D., F.I.C., F.R.S., Past President, British Association. Cleveland Lodge, Dorking. I, II.

Jones, Dr. Ernest, President, International Psychoanalytical Association, 81, Harley Street, London, W. 1.

Jones, Ll. Wynn, Ph.D., Lecturer in Experimental Education in the University of Leeds. 7, Bideford Avenue, Roundhay, Leeds. I, II.

Jung, Prof. C. G., Professor of Psychology in the University of Zurich. I.

Keith, Major J., Pitmedden, Udney, Aberdeenshire. I, II.

Keith, Mrs. Pitmedden, Udney, Aberdeenshire. I, II.

Kelly, Miss E. E., Chemical Laboratories, Brownlow St., Liverpool. I.

Kinvig, R. H., Reader in Geography in the University of Birmingham. 36, Oakfield Rd., Selly Park, Birmingham. I, II.

Lennard-Jones, Prof. J. E., Ph.D., D.Sc., F.R.S., Plummer Professor of Theoretical Chemistry in the University of Cambridge. Corpus Christi College, Cambridge. I, (? II).

Mapother, Dr. Edward, Medical Superintendent and Lecturer in Psychological Medicine, Maudsley Hospital, London.

McFarlane, J., Reader in Geography in the University of Aberdeen. Marischal College, Aberdeen. I, (? II).

Myers, C. S., C.B.E., M.D., Sc.D., D.Sc., F.R.S., Principal of the National Institute of Industrial Psychology, Aldwych House, Aldwych, W.C. 2. I.

Ogg, W. G., Ph.D., Lecturer in Soil Science in the University of Aberdeen. Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen. I, (? II).

Ogilvie, Prof. A. G., O.B.E., Professor of Geography in the University of Edinburgh. 40, Fountainhall Rd., Edinburgh. I.

Peake, E. J. E., F.S.A., Ex-President of the Royal Anthropological Institute. Westbrook House, Newbury, Berks. I.

Poulton, E. P., M.D., F.R.C.P., Physician to Guy's Hospital, London. 25, Upper Wimpole St., W. 1. I, II.

Poulton, Miss J. 25, Upper Wimpole Street, W. 1. I, II.

Read, Prof. H. H., D.Sc., George Herdman Professor of Geology in the University of Liverpool. I (after Delhi).

Rendle, A. B., D.Sc., F.R.S., Lately Keeper of the Department of Botany, British Museum, Talland, The Mount, Fetcham Park, Leatherhead, Surrey. I, II.

Robinson, Prof. H. R., Ph.D., D.Sc., F.R.S., Professor of Physics in the University of London (Queen Mary College). 44, Belsize Park Gardens, N.W. 3. I.

Salaman, R. N., M.D., F.R.S., Director, Potato Virus Research Station, School of Agriculture, Cambridge. Homestall, Barley, Royston, Herts. I, (? II).

Salaman, Mrs., Homestall, Barley, Royston, Herts. I (? II).

Samuel, The Rt. Hon. Lord, P.C., G.C.B., President, British Institute of Philosophy. 32, Porchester Terrace, London, W. 2.

Samuel, Lady, 32, Porchester Terrace, London, W. 2.

Sewell, Lt.-Col. R. B. Seymour, C.I.E., Sc.D., F.R.S., Formerly Director of the Zoological Survey of India. Zoological Laboratory, The Museums, Cambridge.

Simonsen, Prof. J. L., D.Sc., F.R.S., Professor of Chemistry, University College of North Wales. The Lawn, Bangor, N. Wales. I, II.

Simonsen, Mrs., The Lawn, Bangor, N. Wales. I, II.

Southwell, Prof. R. V., F.R.S., Professor of Engineering Science in the University of Oxford. 9, Lathbury Road, Oxford. I, (? II).

Spearman, Prof. C., Ph.D., LL.D., F.R.S., Emeritus Professor of Psychology in the University of London. 67, Portland Court, W. 1. I, II.

Stamp, L. Dudley, D.Sc., Sir Ernest Cassel Reader in Economic Geography in the University of London. Popa, Ashtead, Surrey. I, II.

Stamp, Mrs., Popa, Ashtead, Surrey. I.
Stephens, G. Arbour, M.D., Consulting Cardiologist, King Edward VII Welsh National Memorial Association. 61, Walter Rd., Swansea. I, II.
Stephens, Mrs. Arbour (Prof. Mary Williams, D.-Litt., Professor of French Language and Literature in University College, Swansea). 61, Walter Rd., Swansea. I, II.
Stratton, Prof. F. J. M., D.S.O., O.B.E., Professor of Astrophysics in the University of Cambridge. Caius College, Cambridge. I, II.
Straub, Prof. W., Professor of Physiology in the University of Muinch. I.
Tattersall, Prof. W. M., Professor of Zoology in the University College of South Wales, Cardiff. University College, Newport Rd., Cardiff. I, (? II).
Tattersall, Mrs., University College, Newport Rd., Cardiff. I, (? II).
Thomas, Prof. F. W., (Anthropology Section), University of Oxford.
Tizard, Sir Henry, C.B., F.R.S., Rector of the Imperial College of Science and Technology. 161, St. James's Court, Buckingham Gate, S.W.L. I.
Tutton, A. E. H., D.Sc., F.R.S., formerly H.M. Inspector of Schools; researches in crystallography, etc. Yew Arch, Dallington, Sussex. I, II.
Vaughan, W. W., M.V.O., D.Litt., formerly Headmaster of Rugby School. The Manor House, Princes Risborough, Bucks. I, (? II).
Vaughan, Mrs., The Manor House, Princes Risborough, Bucks. I, (? II).
Veltheim, Baron von, Psychologist, Castle Ostean, near Halle-Saale, Germany.
Venn, J. A., Litt.D., President of Queen's College and Lecturer in the History and Economics of Agriculture in the University of Cambridge. The President's Lodge, Queen's College, Cambridge. I, (? II).
White, Prof. R. G., Professor of Agriculture in the University College of North Wales, Bangor. University College, Bangor, N. Wales. I.

Baptist Mission Press, Calcutta.

INDIAN SCIENCE CONGRESS

Presidential Address[1]

Congress President-Elect :—

PROF. THE RT. HON. LORD RUTHERFORD OF NELSON,
O.M., F.R.S., D.Sc., LL.D., PH.D.

During the past fifty years, the British Association for the Advancement of Science has been invited on many occasions to hold its meetings overseas. Four times it has journeyed to Canada (Montreal 1884, Toronto 1897, Winnipeg 1909, Toronto 1924), twice to South Africa (1905, 1929), once to Australia (1914). This policy of the Association of arranging occasional meetings in our Dominions has proved an unqualified success. These overseas visits have had a marked influence on the progress of science throughout our Commonwealth and by personal contacts have helped much to promote mutual understanding and co-operation between our peoples.

The visit of a representative group of scientific men to our most distant Dominions in 1914, in itself an outstanding event in the history of the Association, was rendered even more notable by the dramatic circumstances under which the meetings were held, for the arrival of the party in Australia coincided with the news of the outbreak of the Great War. No one who like myself took part in the meetings in Australia and New Zealand in those troubled but stirring times can ever forget the warmth of our reception. We were privileged to witness that wonderful response of the peoples of these lands to the call of danger—a response which we know grew ever greater with the need.

It has long been the wish of the British Association to hold a meeting in India, but difficulties of time and climate have stood in the way of its realization. It has been found most convenient for the overseas visits to take place in the summer months but such a time is quite unsuitable for India. This difficulty would be in part surmounted if a representative party of scientific men could obtain leave of absence from their duties to visit India during the cold weather.

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1 Received after Lord Rutherford's death.

The celebration of the Silver Jubilee of the founding of the Indian Science Congress Association offered a suitable occasion for such a visit, and arrangements have been made by the two Associations to hold a joint meeting in India. I gladly accepted the invitation of the two bodies to preside over this combined meeting. I feel it not only a great honour but a great privilege and responsibility to be asked to fill this post on such an historic occasion. This visit of the British Association to your shores is a symbol of our desire to extend the hand of greeting and fellowship to our sister society and also individually to our co-workers in science in India.

While science has no politics, I am sure it is of good omen that our visit happens to fall at a time when India is entering upon a new and important era of responsible co-operative government in the success of which both our countries are deeply concerned.

On behalf of the British Association, I extend to the Indian Association our warmest congratulations on this the twenty-fifth anniversary of its foundation and our sincere wishes for its continued success. We recognize that your Association, both in its constitution and its aims so closely resembling the British Association, has proved of great service to the progress of science throughout India. Founded at a time when the Universities were becoming centres of original research, it afforded to a widely scattered scientific community a much needed common meeting ground for the discussion of scientific problems. It helped also to bring to the attention of the interested public the importance of science and of the scientific method in national development. I think it can be safely stated that the success of the meetings of the Indian Association in no small degree influenced the later foundation of specialist societies in India, for example, the Chemical Society and Physics Society.

On such an occasion as this, we must not forget to do honour to those who were largely instrumental in founding your Association and in guiding its infant steps. I would refer in particular to Professor J. L. Simonsen, Professor P. S. MacMahon and your senior Past-President, Sir Sydney Burrard. The Association owed much in its early days to the friendly support and encouragement so freely given by that premier Indian Society, the Royal Asiatic Society of Bengal of which I am proud to be an honorary Fellow.

In earlier days in India, research was largely confined to the great official scientific services, initiated and maintained on a gererous scale by the Indian Government, for example, the Survey of India, the Geological Survey, the Botanical Survey, the Departments of Agriculture and Meteorology and many others. Pioneer work of outstanding scientific importance has been done by all these services. In the short time at my disposal, I can only make a passing reference to a few items of work

accomplished, and can mention only a few of the array of distinguished names which have been connected with these great scientific services.

The Trigonometrical Survey of India has a long and distinguished history. The splendid series of geodetic measurements along an arc from Cape Comorin to the Himalayas, made by Everest, was of outstanding importance and his name is for ever associated with the highest peak in the world. As a result of this survey, the deflections of a plumb line, due to the gravitational attraction of the Himalayan range, were determined at different points. A careful comparison of the results of observation with calculation, largely due to the work of Archdeacon Pratt of Calcutta, and later of Sir Sydney Burrard, disclosed marked discrepancies, the effect of the mountain mass at a distance being much less than was expected. Attempts to explain these and other anomalies ultimately led to the formulation of a new and important theory of mountain formation known as the principle of isostasy. On this hypothesis, the excess pressure due to a mountain mass is compensated for by a deficiency of matter below its base. This conclusion, which is in accord with extensive gravitational as well as geodetic measurements in India, is believed to be of general application to mountain formation throughout the world.

I may recall that a former distinguished Superintendent of this Survey, Sir Gerald Lenox Conyngham, is now Head of the Department of Geodesy in Cambridge.

The Geological Survey, one of the oldest scientific services in India, has a fine record of work accomplished and its survey of the mineral resources of India has proved of great value to Indian industry. Among many distinguished names, I may specially mention that of Sir Thomas Holland, a former Director, who has done such good work for your country in peace and war. I believe that it was largely due to his energy and scientific insight that the great Tata Iron and Steel Works were begun.

The Department of Meteorology has done much pioneering research and was one of the first to realize the importance of studying the conditions of the upper air by means of small balloons—a subject of ever-increasing importance with the advent of the aeroplane. I have always felt a friendly interest in this Department as many of its members are known to me personally. Amongst them is Sir Gilbert Walker, a former Director and once President of this Association, who did much to improve the Meteorological Service in India and himself made important original contributions to our knowledge of the South-West Monsoon. I may recall that the present distinguished head of the Meteorological Office of Great Britain, Sir George Simpson, was for many years a member of this Indian Department.

The study of the botanical riches of India owes much to the work of Roxburgh, Wallich and Prain, and also that explorer

and naturalist, Hooker, whose work on the flora of British India is known to you all.

In Forestry, India has at Dehra Dun probably the finest research laboratory of its kind in the world. We in England owe a debt of gratitude to India in providing us with our distinguished Professor of Forestry at Oxford, Professor R. S. Troup, and the first two directors of our Forest Products Laboratory, namely Sir Ralph Pearson and Mr. W. A. Robertson.

While in this brief survey I can mention only a few departments out of many, yet I must not omit to refer to the great advances in knowledge due to the Indian Medical Service, so well represented by the pioneer work of Ross on malaria and by Leonard Rogers on cholera and leprosy, researches which gave new hope to the peoples of India.

In the early days of the Indian Universities, attention was mainly directed to teaching and examining the large number of students who presented themselves, and comparatively little attention was paid to research. There were always a few, however, who recognized that the universities had a wider part to play in Indian education, and should become centres of research as well as of teaching. Amongst those pioneers who distinguished themselves by original investigations and by the stimulation of others, I should particularly mention Sir Alexander Pedler, Sir Alfred Bourne, Sir Jagadis Bose and Sir Prafulla Ray, and it is of interest to recall that the last three have all been presidents of your Association.

As a result of the Curzon Commission on Education in 1904, many of the universities introduced honours courses, and by new appointments and improvements in laboratories stimulated research in science. Excellent well-equipped schools of research have arisen in many Indian universities, where good opportunities are available for the training of potential investigators in the methods of research. The Indian student has shown his capacity as an original investigator in many fields of science, and, in consequence, India is now taking an honourable part and an ever-increasing share in the advance of knowledge in pure science.

Amongst many workers of distinction, I may specially mention Sir Venkata Raman, Professor M. N. Saha and Professor B. Sahni, each of whom has made outstanding contributions. That premier scientific society of Great Britain, the Royal Society, has recognized the value of their work by election to its Fellowship.

We in Great Britain watch with pride this growth of the scientific spirit in India and are pleased to help in any way we can. As an example of our interest, I may recall that Trinity College, Cambridge—my own college—assisted that mathematical genius Ramanujan to prosecute his studies in Cambridge. He was soon elected a Fellow of that College and a Fellow of the

Royal Society. But for his premature death, it may be said of him, as Newton said of Cotes, that we had known something.

The researches in astrophysics of S. Chandrasekhar in Cambridge were soon recognized by the award to him of an Isaac Newton Studentship and later by his election to a Fellowship in Trinity College.

As a member of the Royal Commission for the Exhibition of 1851, I would like to refer to some events this year of special interest to India. This Commission awards each year a number of Overseas Scholarships to our Dominions, as well as Senior Research Studentships open to competition in England by all members of our Commonwealth. The opportunity offered by these scholarships to promising investigators from overseas to continue their work in England or abroad has proved of great value to the progress of science. I am proud to remember that I myself was awarded an 1851 Scholarship on the recommendation of the University of New Zealand.

It has for some time been the wish of the 1851 Commission to be able to offer one or more of its Overseas Scholarships for award to students in India. Owing to difficulties of finance, it was only this year that this project was realized. A preliminary committee of selection was set up in India and the Commissioners with whom lay the final choice have appointed Mr. N. S. Nagendra Nath of the Indian Institute of Science, Bangalore, as the first 1851 Exhibition Scholar from India. He will proceed to Cambridge to carry out investigations in Theoretical Physics. For the first time also, an Indian student in Cambridge, Dr. H. J. Bhabha, has been awarded in open competition one of our valuable Senior 1851 Studentships in recognition of the importance of his researches in Theoretical Physics. The Commission would like to be in a position to allot a second Science Scholarship to India but funds are insufficient. The machinery, however, is there, and I know that the Commissioners would be only too happy to administer a second award if anyone in India, who is interested in her scientific progress, were generous enough to provide the necessary endowment.

While, as we have seen, the universities of India have in later years made substantial progress both in teaching and research in science, yet it must be borne in mind that still greater responsibilities are likely to fall on them in the near future. This is in a sense a scientific age, where there is an ever-increasing recognition throughout the world of the importance of science to national development. A number of great nations are now expending large sums in financing scientific and industrial research with a view to using their natural resources to the best advantages. Much attention is also paid to the improvement of industrial processes and also to conducting researches in pure science which it is hoped may ultimately lead to the rise of new industries.

It is natural to look to the universities and technical institutions for the selection and training of the scientific men required for this development. In India, as in many other countries, there is likely to be a greater demand in the near future for well-trained scientific men. With the growth of responsible government in India, it is to be anticipated that the staff required for the scientific services in India and for industrial research will more and more be drawn from students trained in the Indian universities. It is thus imperative that the universities should be in a position not only to give a sound theoretical and practical instruction in the various branches of science but, what is more difficult, to select from the main body of scientific students those who are to be trained in the methods of research. It is from this relatively small group that we may expect to obtain the future leaders of research both for the Universities and for general research organizations. This is a case where quality is more important that quantity, for experience has shown that the progress of science depends in no small degree on the emergence of men of outstanding originality of mind who are endowed with a natural capacity for scientific investigation and for stimulating and directing the work of others along fruitful lines. Leaders of this type are rare but are essential for the success of any research organization. With inefficient leadership, it is as fatally easy to waste money in applied research as in other branches of human activity.

The selection of such potential investigators and leaders is not an easy task, for success in examinations in science is no certain criterion that the student is fitted for a research career. A preliminary training in research methods for a year or two is required to select those who possess the requisite qualities of originality and aptitude for investigation. A system of grants-in-aid or scholarships to approved students may be required for such postgraduate training. In Great Britain the financial help given by the Universities and other educational institutions for training in research is in many cases supplemented by maintenance grants to promising students, awarded by the Department of Scientific and Industrial Research. This system has proved of much value both in developing the research activities of the universities and in providing a supply of competent men both for research in pure science and in industry.

I have so far mentioned some aspects of the scientific work carried out by the universities and government services of India. I am well aware that much attention has also been directed to the need of scientific research in agriculture, and in certain industries. An Indian Cotton Committee has been set up which has given admirable service, while the Indian Lac Cess Committee arranges for investigations in that unique Indian product, some of which are carried out in Great Britain. I am interested to know that an Agricultural Research Council has recently

been formed, largely as a result of the findings of a Commission of which His Excellency the Viceroy was Chairman.

While I cannot lay claim to have any first-hand knowledge of Indian industries and conditions, yet perhaps I may be allowed to make some general observations on the importance in the national interest of a planned scheme of research in applied science. If India is determined to do all she can to raise the standards of the life and health of her peoples and to hold her own in the markets of the world, more and more use must be made of the help that science can give. Science can help her to make the best use of her material resources of all kinds, and to ensure that her industries are run on the most efficient lines. National research requires national planning. If research is to be directed in the most useful direction, it is just as important for a nation as for a private firm to decide what it wishes to make and sell. It is clear also that any system of organized research must have regard to the economic structure of the country. One essential fact at once stands out. India is mainly an agricultural country, for more than three-quarters of her people gain their living from the land, while not more than three per cent. are supported by any single industry. A glance at the official review of the trade of India shows that the annual production of wheat has risen since 1914 from about 8·3 to 9·5 million tons, while exports in the same period have fallen from over a million tons to 10,000 tons. In the case of another important food, rice, the Indian production, exclusive of Burma, has remained fairly steady, varying between 22 and 25 million tons annually, but here also exports have fallen from about half a million tons before the War to about 200,000 tons.

In view of these facts, it would seem clear that, in any national scheme of research, research on foodstuffs has a primary claim on India's attention. Quite apart from improvements in the systems of agriculture used in India, there is a vast field for the application of scientific knowledge to the improvement of crops, for example, by seeking for improved strains suitable for local conditions, by research on fertilizers and in many other directions. The fact that surplus wheat for export has decreased suggests that the present production is required for home consumption in India. When the permanent schemes of irrigation now in hand bring much more land under full cultivation, India may again wish to take her place in the export market. To do this in the face of international competition, well-planned agricultural research will be essential.

While the character of India's trade has seen many changes in the last hundred years, to-day exports of cotton, jute and tea amount to about 60 per cent. of the total exports of India. Next in importance come oil and seeds 6 per cent., hides 5 per cent. and lac 1 per cent. There is no doubt that more scientific knowledge would increase the production of all these products.

There is of course the need to make sure that there is a market for such a surplus. Of India's standard exports, cotton represents about 20 per cent. of the total value. In spite of recent strenuous attempts to improve Indian cotton, its staple is still usually looked upon in the world's markets as short and coarse. No doubt there are purposes for which cotton of this type possesses special advantages, though the demand for it must now be very near to saturation point. Still, India only produces about 16 per cent. of the world's cotton crops and there appears to be no reason why it should not produce a larger share; but until the cultivation of better varieties is more extensive, competition with cottons of the American type in the world markets will certainly be difficult. Here there appears to be a wide field for applied research. Good work has been done by the Indian Cotton Committee which has taken steps to improve the staple and prevent adulteration and inter-mixture of various varieties. The problem can be approached, however, not only in the seeking of better varieties but in finding uses and methods of treatment for the short staple variety. The importance of research on the cotton itself is well brought home by the results achieved in the United Kingdom, where the British Cotton Industry Research Association at the Shirley Institute has found that many of the defects which appear in the finished article can be traced back to defects in the raw material.

Finally a word might be said concerning the need for research on radio-communication, so important a matter to a large country like India. I do not refer to technical research in transmitting and receiving apparatus, but rather to the type of fundamental investigation pursued under the Radio Research Board in Great Britain. These investigations, begun in the early days after the War, have shown that the propagation of radio-waves over large distances is very sensitive to the electrical state of the upper atmosphere. It is now established that a number of electrified layers exist in the higher atmosphere which under certain conditions are able to reflect electric waves. The details of this electrical distribution vary considerably with the hour of the day and with the season of the year, as well as with geographical location. Such information, which is of practical importance in the selection of the most suitable wave-lengths for radio-communication, must obviously be secured by research conducted in the country itself. Moreover, it does not seem impossible that such a survey may prove of value in long range weather forecasting.

There is here, then, much scope for research in a wide field, which I hope will be pursued vigorously in India. It is pleasant to note that a most promising beginning in tackling fundamental radio problems of this character has already been made here by Professors M. N. Saha and S. K. Mitra and their students.

The importance of survey work of this kind has already been recognized in other parts of the Empire, where it has received official support and encouragement. I will refer in particular to the admirable work in this field by the Radio Research Board of Australia.

Industrial Research in Great Britain.

While I recognize the great differences which exist between the industrial and agricultural conditions in Great Britain and India, yet it may prove of some interest and, I hope, of some value, if I give a brief account of some of the ways in which the British Government has aided industrial and agricultural research in the period following the Great War. From the dawn of the scientific age, Great Britain has taken a prominent place in advancing knowledge both in pure research in our universities and in applied research for the development of industry. Before the War, progress in industry depended in the main on the brilliant contributions of individual workers rather than on any systematic attack by scientific methods on the problems of industry. We may instance the pioneer work of Bessemer for the steel industry and of Parsons in the development of the steam-turbine which had such a great effect on the power-industry. One cannot pay too high a tribute to the greatness of the achievements of individual inventors and investigators such as these, for it was largely due to them that Great Britain obtained so great an industrial position in the last century.

Yet I think it is true to say that in the period before the War the country as a whole failed to recognize as fully as some other nations the importance of an organized scientific attack on broad lines on the problems of industry. In a number of cases, British science gave ideas to the world, but it was left to other nations to develop them by intensive research and to reap the industrial benefit.

This weakness in our organization became apparent in the War when the production of munitions and materials threw a great strain on industry. The common danger brought the industrialist and man of science into close co-operation to their mutual benefit. The results of this co-operation surpassed all expectation. New chemical processes were evolved, many new devices arose, while communications were revolutionized by the rapid development of the thermionic valve. In a hundred different ways, the co-operation of science with industry had justified itself by its success.

Early in the War, the British Government recognized that when peace came, a more systematic application of science and research over a broader field was essential in the national interest and, amid the distractions of war, set up the necessary machinery to accomplish this. In 1915 the Department of Scientific and Industrial Research was formed, and a few years later in 1920

the Medical Research Council was set up to undertake investigations in all matters connected with the health of the people. This was followed in 1931 by the formation of the Agricultural Research Council. The formation of the Department of Scientific and Industrial Research marked the first comprehensive and organized measure taken in Great Britain to help industry generally through the application of science. A number of new research organizations were set up, controlled and financed by the Department, to deal with the scientific aspects of the use of fuel, of the storage and transport of food, of buildings and later of roads—subjects of great importance to the common welfare of the people but on which little if any organized research had been undertaken.

Coal is the greatest material asset possessed by Great Britain, for on it mainly depends the heating of our homes and the production of power for most industries. Its better utilisation is a problem of great national importance. To achieve this purpose, the Fuel Research Board was formed and a large laboratory was erected at Greenwich to carry out investigations on the better and more economic use of coal. An important section of this work is a national survey of the coal resources of Great Britain carried out in special laboratories in the several coalfields. The properties of the coal in the various seams are carefully examined and, if necessary, full scale trials are made at the Fuel Research Station to test the suitability of the coal, for example, for carbonization, for steam raising or for conversion into oil. The results of this survey, which is still in progress, have proved of increasing value not only to the colliery owner and the industrialist but also for the needs of the export trade.

In Great Britain every year upwards of 100 million pounds are spent on the erection of new buildings and in maintaining old ones, yet no organized research on buildings had been made. To remedy this deficiency, the Department set up a Building Research Station near London where investigations are made on the many and varied problems connected with the better housing of the people. For example, investigations are carried out to find a scientific explanation of the traditional practices which have grown up in the building trade, for on this depends a rational adjustment of materials and methods to meet modern needs. The results of such a scientific enquiry in this comparatively unexplored field cannot fail to have a marked influence on building construction generally.

The Building Research Station embraces in its programme all problems connected with building materials except those associated with the use of timber. These are dealt with at another establishment of the Department, the Forest Products Research Laboratory. Here intensive researches are carried out on the best use of timber and its preservation. The country spends large sums annually on timber, much of it imported, and

in the national interest it is of great importance to us that the best value is obtained for this outlay.

You are all aware that food represents one of Great Britain's largest imports, and much of this is transported great distances from overseas. An organization was set up known as the Food Investigation Board, to consider the best methods of storage and transport of food, so as to avoid waste and loss of nutritive value. Much of this work has its centre at the Low Temperature Research Station in Cambridge, but a special station at Torry, Aberdeen, deals with the preservation of fish and another at Ditton in Kent with the storage of fruit. Investigations in this field, which owe so much to the initiative of the late Sir William Hardy, have proved very valuable in many directions, and have led to great improvements in the conditions of transport and storage of a great variety of food stuffs.

I may give one example out of many of the striking consequences of such researches. The Low Temperature Research Station found that beef in a chilled state could be safely stored for 60 or 70 days in a suitable atmosphere of carbon dioxide. The importance of this discovery, which enabled beef to be carried in first rate condition from our most distant Dominions, was at once recognized by the interests concerned. The first shipment of chilled beef carried by this new method of gas storage was landed in 1929 from New Zealand. Since that time, shipments from Australasia have steadily increased, and most of the vessels built for the Australasian trade have now chambers specially constructed for transport in gas storage.

While the development of our roads in the past owes much to the pioneer work of men like Macadam and Telford, there was no planned organization to add to our knowledge of road construction until comparatively recent years, when the Road Research Station was set up at Harmondsworth near Slough to deal with problems of road construction and the study of road wear under modern conditions of traffic. When we consider the large sums spent every year on the construction and maintenance of roads, the need of such scientific investigation is obvious.

The group of research organizations so far considered deals with the primary needs and interests of the people as a whole as regards food, fuel, building and roads. No independent establishment was set up to deal with another important need of the people, namely clothes, for this is most appropriately provided for by the large research associations which have been instituted in connection with the cotton, wool, and linen industries.

Of the national organizations under the charge of the Department, the largest and probably the most important is the National Physical Laboratory at Teddington, which covers about 50 acres and employs a staff of nearly 700 persons. The work of this Laboratory, primarily intended for the assistance of industry

in general, covers a very wide field. It has eight great departments devoted to the study of the different branches of Physics, Electrotechnics, Engineering, Metallurgy and Metrology, Radio-communications, Aero-dynamics and the investigation of ship design. The Laboratory is responsible for the maintenance of the National Standards and for refined measurements connected with them. It is not always realized to what a great extent modern mass production depends on the maintenance of exact standards and the Laboratory plays an important part in testing the accuracy of gauges so necessary in modern industry.

In 1925 a Chemical Research Laboratory was set up at Teddington, in which pioneer work is being carried out on chemical reactions at high pressures and temperatures and in the production of synthetic resins. Another important problem in which the Department is interested is the provision of more plentiful supplies of pure water for domestic and industrial consumption. Valuable work has been done by the Water Pollution Research Board in many directions, and new methods have been found for the purification of water which has been contaminated by the industrial effluents from sugar and milk factories.

I have so far mentioned research organizations which have been set up to encourage the application of science to problems which affect the daily life of the people and the nation's industries considered as a whole. I should mention that these national organizations to which I have referred are not only willing but anxious to co-operate with corresponding institutions which may be set up in India or the Dominions.

I must now refer to arrangements which have been made to promote the application of scientific knowledge to the problems of the individual industries. The importance of research has long been recognized by large industrial companies, who have in many cases set up research establishments for their own requirements. This tendency is specially marked in the electrical and chemical industries, where large sums are spent annually on research.

It is, however, to be borne in mind that a great part of British industry is carried out in small establishments. A survey carried out some years ago indicated that in 128,000 factories in Great Britain less than 500 employed more than 1,000 workers while over 117,000 employed less than 100 workers. Obviously such small factories are not in a position to maintain a research laboratory on anything but a small and inefficient scale. To overcome this difficulty, the Department in conjunction with industry instituted a number of co-operative research associations representing the greater part of the main industries of the country. Each of these research associations is autonomous and controlled by representatives of the industry concerned, and is financed by contributions from the firms belonging to the association, assisted by grants from the Department,

This bold experiment in the co-operative organization of research, which is unique in the world, has undoubtedly proved a great success. To-day there are twenty such research associations formed on a national basis in their respective industries and for membership of which all British firms are eligible. They cover the metal and textile industries, paint, leather, boots and shoes, rubber, flour milling, cocoa and confectionery, food, printing, scientific instruments and the automobile and electrical industries. From small beginnings, a number of these associations have steadily grown in size and strength until they now form an indispensable and valuable part of the industries they represent.

I can speak with some knowledge of the marked progress made by these two types of research organization, as I have been privileged, as Chairman of the Advisory Council of the Department of Scientific and Industrial Research for the past 8 years, to come in close contact with them. While much still remains to be accomplished, there has been a great advance in recent years in the recognition of the value of research in increasing the efficiency of industry. If we are to hold our own in face of the ever increasing competition in the world to-day, it is essential that our industries should take full advantage of the resources which science places at their disposal.

It is of interest to note that the Overseas Dominions have not been slow to appreciate the importance of such national organizations in the development of their national resources and industries. Healthy research organizations under the control of National Research Councils or corresponding bodies have been set up in Canada, Australia, New Zealand and South Africa. Both in Canada and Australia, which have a Federal system of Government, the research organization is national in the true sense of the word, and responsible only to the central Government.

It is to be borne in mind that the organization of research for industry and for general national purposes varies much in different countries. A research organization which may prove adequate for a country like Great Britain may prove quite unsuitable for another country with different needs and different industrial conditions. In developing any organized scheme of research, each country must consider its own resources and its own particular requirements. As we have seen, the organization of research not only in Great Britain but in the Dominions, is national in scope. Even in a large country like India, where the resources and needs of the different Provinces are very varied, it seems to me essential for efficiency that the organization of research should be on national rather than on provincial lines. The setting up of separate research establishments for similar purposes in the various provinces cannot but lead to much overlapping of work and waste of effort and money. Such a central organization of research does not necessarily mean that the scientific work should all be concentrated in a

single laboratory. For example, I understand that a single organization is responsible for the research in cotton for the whole of India. While the more fundamental research is done at a conveniently situated laboratory, much of the work of a special character is carried out in the provinces where cotton is grown.

In Great Britain, the responsibility for planning the programmes of research, even when the cost is borne directly by the Government, rests with research councils or committees who are not themselves State servants but distinguished representatives of pure science and industry. It is to be hoped that if any comparable organization is developed in India, there will be a proper representation of scientific men from the universities and corresponding institutions and also of the industries directly concerned. It is of the highest importance that the detailed planning of research should be left entirely in the hands of those who have the requisite specialized knowledge of the problems which require attack. In the British organizations there is no political atmosphere, but of course the responsibility for allocating the necessary funds ultimately rests with the Government.

In this address, I have to a large extent confined my attention to research in pure science, agriculture and industry. I am, however, not unmindful of the pressing needs of India to alleviate the sufferings of the people from attacks of malaria and other tropical diseases. I know that India herself is giving much thought to these vital problems in which science can give her valuable help.

Transmutation of Matter.

I have so far spoken of the importance of science as a factor in national development, but before concluding my address, I would like to refer to some investigations in pure science in which I have been personally much interested. I refer to the successful attack on that age-old problem of the transmutation of matter which in recent years has attracted so much attention from physicists throughout the world.

I hope it may prove of interest to give a brief account of the successive stages of the growth of our knowledge of this subject, for it illustrates in a striking manner the power of the scientific method of attack on what at first appeared to be an insoluble problem. Incidentally these researches have yielded us precious information on the structure of all atoms and indeed it seems likely to have provided us with a key, so to speak, to unlock the secrets of the constitution of our material world.

Towards the close of the nineteenth century, when it seemed certain that the atoms of the elements were unchangeable by the forces then at our command, the discovery was made which

has revolutionized our conception of the nature and relations of the elements. I refer to the discovery in 1896 of the radioactivity of the two heaviest elements uranium and thorium. It was soon made clear that this radioactivity is a sign that the atoms of these elements are undergoing spontaneous transmutation. At any moment, a small fraction of the atoms concerned becomes unstable and breaks up with explosive violence, hurling out either a charged atom of helium, known as an α-particle, or an electron called in this connection a β-particle. As a result of these explosions, a new radioactive element is formed and the process of transmutation once started continues through a number of stages. Each of the radioactive elements, formed in this way, breaks up according to a simple universal law but at very different rates. In a surprisingly short time, these successive transformations were disentangled and more than 30 new types of elements brought to light while the simple chemical relations between them were soon made clear.

We had thus been given a vision of a new and startling sub-atomic world where atoms break up spontaneously with an enormous release of energy, quite uninfluenced by the most powerful agencies at our disposal. Apart from uranium and thorium and the elements derived from them, only a few other elements showed even a feeble trace of radioactivity. The great majority of our ordinary elements appeared to be permanently stable under ordinary conditions on our earth. Science was then faced with the problem whether artificial methods could be found to transmute the atoms of the ordinary elements. Before this problem could be attacked with any hope of success, it was necessary to know more of the actual constitution of atoms. This information was provided by the rise of the nuclear theory of the atomic structure which I first suggested in 1911. The essential controlling feature of all atoms was found to reside in a very minute central nucleus which carried a positive charge and contained most of the mass of the atom. A relation of unexpected simplicity was found to connect the atoms of all the elements. The ordinary properties of an atom are defined by a whole number which represents the number of units of resultant positive charge carried by the nucleus. This varies from 1 for hydrogen to 92 for the heaviest element uranium and with few exceptions all the intervening numbers correspond to known elements.

On this view of atomic structure, it was evident that, to bring about the transmutation of an atom, it was necessary in some way to alter the charge or mass of the nucleus or both together. Since the nucleus of an atom must be held together by very powerful forces, this could only be effected by bringing a concentrated source of energy in some way to bear on the individual nucleus. The most energetic projectile available at that time was the α-particle spontaneously ejected from radio-

active substances. If a large number of α-particles were fired at random at a sheet of matter, it was to be expected that one of them must occasionally approach very closely to the nucleus of any light atom in its path. In such a close encounter, the nucleus must be violently disturbed, and possibly under favourable conditions the α-particle might actually enter the nuclear structure, resulting in a transformation of the nucleus.

This mode of attack upon the nucleus at once proved successful. I found in 1919 that nitrogen could be transformed by bombardment with fast α-particles. The process of transmutation is now clear. Occasionally an α-particle actually enters the nitrogen nucleus and forms with it a new unstable nucleus which instantly breaks up with the emission of a fast proton (hydrogen nucleus) and the formation of a stable isotope of oxygen of mass 17. About a dozen of the light elements were found to be transformed in a similar way. The protons liberated in the nuclear explosions were at first counted by observing the flashes of light (scintillations) produced in phosphorescent zinc sulphide. This method was slow and very trying to the eyes of the observers. Progress however became more rapid and definite when electrical methods of counting individual fast particles were developed. These electrical counters, mainly depending on the use of electron-tubes for magnifying small currents, have now reached such a stage of perfection that we are able to count automatically individual fast particles like α-particles and protons, even though they enter the detecting chamber at a rate as fast as ten thousand per minute. By other special devices, we are in like manner able to count individual β-particles. In this connection, I must also mention that wonderful instrument the Wilson Expansion Chamber which makes visible to us the actual tracks of flying fragments of atoms resulting from an atomic explosion. These remarkable devices have played an indispensable part in the rapid growth of knowledge during the last few years. It is to be emphasized that progress in scientific discovery is greatly influenced by the development of new technical methods and of new devices for measurement. With the growing complexity of science, the development of special techniques is of ever increasing importance for the advance of knowledge.

Up to the year 1932, experiments on transmutation were confined to the use of α-particles for bombarding purposes. It became clear that the process of transformation was in most cases complex, since groups of protons with different but characteristic energies were observed when a single element was bombarded. This led to the conception that discrete energy levels existed within a nucleus and that under some conditions part of the excess energy was sometimes released in the form of a quantum of high frequency radiation.

The stage was now set for a great advance, and four new discoveries of outstanding importance were made in rapid succession in the period 1932-3. I refer to the discovery of the positive electron by Anderson in 1932, of the neutron by Chadwick in 1932, of artificial radioactivity by M. and Mme. Curie-Joliot in 1933 and of the transmutation of the elements by purely artificial methods first shown by Cockcroft and Walton in 1932.

The discovery of the neutron—that uncharged particle of mass nearly 1—was the result of a close study of the effects produced in the light element beryllium when bombarded by α-particles. It is noteworthy that the proton and the neutron, which are now believed to be the essential units with which all atomic nuclei are built up, owe their recognition to a study of the transmutation of matter by α-particles.

Before the discovery of the neutron, it had been perforce assumed that nuclei must in some way be built up of massive protons and light negative electrons. Theories of nuclear structure became much more amenable to calculation when the nucleus is considered to be an aggregate of particles like the proton and neutron which have nearly the same mass. There was no longer any need to assume that either the positive or the negative electron has an independent existence in the nuclear structure. We are still uncertain of the exact relation, if any, between the neutron and the proton. The neutron appears to be slightly more massive than the proton but it is generally believed, although no definite proof is available, that the proton and neutron within a nucleus are mutually convertible under certain conditions. For example, the change of a proton into a neutron within the nucleus should lead to the appearance of a free positive electron, while conversely the change of a neutron into a proton gives rise to a free negative electron. In this way it appears possible to account for the observed fact that either positive or negative electrons are emitted by a large group of radioactive elements, to which I will now refer.

In the early experiments on transmutation by α-particles, it was supposed that a stable nucleus was always formed after the emission of a fast proton. The investigations of M. and Mme. Curie-Joliot showed that in some cases elements were formed which, while apparently stable, ultimately broke up slowly, exactly like the natural radioactive bodies. Most of these radioactive bodies, formed by artificial methods, break up with the expulsion of fast negative electrons, but in a few cases positive electrons are emitted. Since the presence of these radioactive bodies can be easily detected, and their chemical properties readily determined, this new method of attack on the problem of transmutation has proved of great value. Nearly a hundred of these radioactive bodies are now known, produced in a great variety of ways. Some arise from the bombardment by fast

α-particles, others by bombardment with protons or deuterons. As Fermi and his colleagues have shown, neutrons and particularly slow neutrons are extraordinarily effective in the formation of such radioactive bodies. On account of its absence of charge, the neutron enters freely into the nuclear structure of even the heaviest element, and in many cases causes its transmutation. For example, a number of these radioactive bodies are produced when the two heaviest elements uranium and thorium are bombarded by slow neutrons. In the case of uranium, as Hahn and Meitner have shown, the radioactive bodies so formed break up in a succession of stages like the natural radioactive bodies, and give rise to a number of trans-uranic elements of higher atomic number than uranium (92). These radioactive elements have the chemical properties to be expected from the higher homologues of rhenium, osmium and iridium of atomic numbers 93, 94 and 95 respectively.

These artificial radioactive bodies in general represent short-lived varieties of the isotopes of known elements. No doubt such transient radioactive elements are still produced by transmutation in the furnace of our sun where the thermal motions of the atoms must be very great. These radioactive elements would rapidly disappear as soon as the earth cooled down after separation from the sun. On this view, uranium and thorium are to be regarded as practically the sole survivors in our earth of a large group of radioactive elements owing to the fact that their time of transformation is long compared with the age of our planet.

It is of interest to note what an important part the α-particle, which is itself a product of transformation of the natural radioactive bodies, has played in the growth of our knowledge of artificial transmutation. It is to be remembered too that our main source of neutrons for experimental purposes is provided by the bombardment of beryllium with α-particles. The amount of radium available in our laboratories is, however, very limited, and it was early recognized that if our knowledge of transmutation was to be extended, it was necessary to have a copious supply of fast particles of all kinds for bombarding purposes. It is well known that enormous numbers of protons and deuterons, for example, can be easily produced by the passage of the electric discharge through hydrogen and deuterium (heavy hydrogen). To be effective for transmutation purposes, however, these charged particles must be given a high speed by accelerating them in a strong electric field. This has involved the use of apparatus on an engineering scale to provide voltages as high as one million volts or more and the use of fast pumps to maintain a good vacuum.

A large amount of difficult technical work has been necessary to produce such high direct voltages, and to find the best methods of applying them to the accelerating system. In Cambridge,

these high voltages are produced by multiplying the voltage of a transformer by a system of condensers and rectifiers ; in the U.S.A. by the use of a novel type of electrostatic generator, first developed by van der Graaf. Prof. E. O. Lawrence of the University of California has devised an ingenious instrument called a 'cyclotron', in which the charged particles are automatically accelerated in multiple stages. This involves the use of huge electromagnets and very powerful electric oscillators. By this method, he has succeeded in producing streams of fast particles which have energies even higher than α-particles ejected from radioactive substances. Undoubtedly this type of apparatus will prove of great importance in giving us a supply of much faster particles than we can hope to produce by the more direct methods.

It was at first thought that very high potentials of the order of several million volts would be required to obtain particles to study the transmutation of elements. Here, however, the development of the theory of wave-mechanics came to the aid of the experimenter, for Gamow showed that there was a small chance that comparatively slow bombarding particles might enter a nucleus. This theoretical conclusion has been completely verified by experiment. In the case of a light element like lithium, transformation effects can be readily observed with protons of energy as low as 20,000 volts. Of course, the possibility of transformation increases rapidly with rise of voltage.

The study of the transmutation of elements by using accelerated protons and deuterons as bombarding particles has given us a wealth of new information. The capture of the proton or deuteron by a nucleus leads in many cases to types of transmutation of unusual interest. For example, the bombardment of the isotope of lithium of mass 7 by protons leads to the formation of a beryllium nucleus of mass 8 with a great excess of energy. This immediately breaks up with two α-particles shot out in nearly opposite directions. When boron of mass 11 is bombarded by protons, a carbon nucleus of mass 12 is formed which breaks up in most cases into three α-particles. The deuteron is in some respects even more effective than the proton as a transmuting agent. When deuterons are used to bombard a compound of deuterium, previously unknown isotopes of hydrogen and of helium of mass 3 are formed, while fast protons and neutrons are liberated. The bombardment of beryllium by very fast deuterons gives rise to a plentiful supply of neutrons. Lawrence has shown that the bombardment of bismuth by very fast deuterons leads to the production of a radioactive bismuth isotope which is identical with the well-known natural radioactive product radium E. Many artificial radioactive elements can be produced often in great intensity. For example, the bombardment of common salt by fast deuterons gives rise to a radioactive isotope of sodium. This breaks up

with a half period of 15 hours, emitting not only fast β-particles but γ-rays at least as penetrating as those from radium.

It may well be that in course of time such artificial radioactive elements may prove a useful substitute for radium in therapeutic work. By these methods also, such intense sources of neutrons can be produced that special precautions have to be taken for the safety of the operators of the apparatus.

Sufficient I think has been said to illustrate the variety and interest of the transmutations produced by these bombardment methods. It should, however, be pointed out that transmutation in some cases can be effected by transferring energy to a nucleus by means of gamma rays of high quantum energy instead of by a material particle. For example, the deuteron can be broken up into its components, the proton and neutron, by the action of the gamma rays from radium or thorium. As a result of the bombardment of lithium by protons, gamma rays of extraordinarily high energy up to 17 million volts are strongly emitted. Bothe has recently shown that these high energy rays are able to transmute a number of atoms, neutrons usually being emitted in the process.

Some simple laws appear to hold in all individual transformations so far examined. Nuclear charge is always conserved, and where heavy particles are emitted, so also is energy when account is taken of the equivalence of mass and energy. Certain difficulties arise with regard to the conservation of energy in cases where light positive and negative electrons are emitted during transmutation, and there is still much discussion on this important question.

The study of the transmutation of matter has been extraordinarily fruitful in results of fundamental importance. In addition to the α-particle, it has disclosed to us the existence of those two building units of nuclei, the proton and neutron. It has greatly widened our conception of the varieties of atomic nuclei which can exist in nature. Not only has it led to the discovery of about one hundred new radioactive elements, but also of several stable isotopes of known elements like ^{3}H, ^{3}He, ^{8}Be which had previously been unsuspected. It has greatly extended our knowledge of the ways in which nuclei can be built up and broken down, and has brought to our attention the extraordinary violence of some of the nuclear explosions which occur. The great majority of our elements have been transmuted by the bombardment method, and in the case of the light elements which have been most carefully studied, a great variety of modes of transmutation have been established.

Rapid progress has been made but much still remains to be done before we can hope to understand the detailed structure and stability of different forms of atomic nuclei and the origin of the elements. I cannot but reflect on the amazing contrast between my first experiment on the transmutation of nitrogen

in the University of Manchester in 1919 and the large-sca experiments on transmutation which are now in progress in many parts of the world. In the one case, imagine an observer in a dark room with very simple apparatus painfully counting with a microscope a few faint scintillations originating from the bombardment of nitrogen by a source of α-particles. Contrast this with the large scale apparatus now in use for experiments on transmutation in Cambridge. A great hall contains massive and elaborate machinery, rising tier on tier, to give a steady potential of about two million volts. Nearby is the tall accelerating column with a power station on top, protected by great corona shields—reminding one of a photograph in the film of Wells's 'Things to Come'. The intense stream of accelerated particles falls on the target in the room below with thick walls to protect the workers from stray radiation. Here is a band of investigators using complicated electrical devices for counting automatically the multitude of fast particles arising from the transformation of the target element or photographing with an expansion chamber, automatically controlled, the actual tracks of particles from exploding atoms.

To examine the effect of still faster particles, a cyclotron is installed in another large room. The large electromagnet and accessories are surrounded with great water tanks containing boron in solution to protect the workers from the effect of neutrons released in the apparatus. A power station nearby is needed to provide current to excite the electromagnet and the powerful electric oscillators.

Such a comparison illustrates the remarkable changes in the scale of research that have taken place in certain branches of pure science within the last twenty years. Such a development is inevitable, for, as science progresses, important problems arise which can only be solved by the use of large powers and complicated apparatus, requiring the attention of a team of research workers. If rapid progress is to be made, such team work is likely to be a feature of the more elaborate researches in the future. Fortunately there is still plenty of scope for the individual research worker in many experiments of a simpler kind.

The science of Physics now covers such a vast field that it is impossible for any laboratory to provide up-to-date facilities for research in more than a few of its branches. There is a growing tendency in our research laboratories to-day to specialize in those particular branches of Physics in which they are most interested or specially equipped. Such a division of the field of research amongst a number of universities has certain advantages, provided that this subdivision is not carried too far. In general, the universities should be left free as far as possible to develop their own lines of research and encouraged to train young investigators, for it cannot be doubted that vigorous

schools of research in pure science are vital to any nation if it wishes to develop effectively the application of science, whether to agriculture, industry or medicine. Since investigations in modern science are sometimes costly and often require the use of expensive apparatus and large scale collaboration, it is obviously essential that adequate funds should be available to the universities to cover the cost of such researches.

In this brief survey, I have tried to outline the contributions to scientific knowledge made in India, and the needs of the immediate future if science is to play its part in the national welfare. While the study of modern science in India is comparatively recent, and naturally much influenced by Western ideas, it is well to recall that India in ancient days was the home of a flourishing indigenous science which in some respects was at the time in advance of the rest of the world.

The study of ancient writings has disclosed in recent years the extent and variety of these scientific contributions. Much progress was made in the study of arithmetic and geometry, while the researches of Sir Prafulla Ray have brought to light the important advances made in metallurgy and chemistry. May we not hope that this natural aptitude for experimental and abstract science, shown so long ago, is still characteristic of the Indian peoples, and that in the days to come India will again become a stronghold of science, not only as a form of intellectual activity but as a means of furthering the progress of her peoples.

SECTION OF MATHEMATICS AND PHYSICS

President :—K. R. Ramanathan, M.A., D.Sc., F.N.I.

Presidential Address

THE EARTH'S MAGNETISM AND THE UPPER ATMOSPHERE.

Introduction.

I have chosen as the subject of my address, 'The Earth's Magnetism and the Upper Atmosphere'. In the seventh session of the Indian Science Congress which was held at Nagpur in 1920, Dr. N. A. F. Moos presided over the section of Mathematics and Physics and spoke on 'Seismology and Earth's Magnetism'. Dr. Moos was the head of the Colaba and Alibag observatories for twenty-five years and his two volumes on 'Colaba Magnetic Data and their Discussion' contain many scholarly studies of an original character and still remain a vast storehouse of information for magnetic data. Dr. Moos is no more with us, but his work lives and inspires.

In recent years, considerable progress has been made in our knowledge of the upper atmosphere—from sounding balloons, investigation of the heights of appearance and disappearance of meteors, reflection of sound waves, atmospheric ozone, light from the night sky and auroræ, regular and irregular variations of the earth's magnetic field and, most fruitful of all, the experimental study of the ionosphere. It was, however, the study of the earth's magnetism that made the first definite contribution to our knowledge regarding the electrical properties of the earth's atmosphere. It still provides a healthy check on theories regarding the upper atmosphere and continues to be suggestive of fresh problems for experimental and theoretical investigation. On the other hand, knowledge derived from other sources is helping to unravel some of the complicated phenomena of the earth's magnetism. My task will be to make a survey of some of the problems, mainly of the earth's atmosphere which a study of its magnetic field has opened up or illuminated.

The Earth's permanent magnetic field and its harmonic analysis.

Exactly a century has elapsed since the foundations of a scientific study of the origin of the earth's magnetism were laid

by C. F. Gauss in his famous 'Allgemeine Theorie des Erdmagnetismus'.[1] Let us recall what he had to say about the aims which have to be kept in view in the study of the earth's magnetism:

'Viewed from the higher grounds of science, even a complete knowledge of the phenomena after this manner (representation of the geomagnetic field by accurate and detailed maps) is not itself the final object sought. It is rather analogous to what the astronomer has accomplished, when for example, he has observed the apparent path of a comet in the heavens. Until the complicated phenomena have been brought in subjection to a common principle, we have only building-stones, not an edifice. The astronomer, after the comet has disappeared from his view, begins his chief employment, and resting on the laws of gravitation, calculates from the observations the elements of its true path, and is thus enabled to predict its future course. And in like manner, the magnetician proposes to himself as the object of his research, as far as the different and in some respects less favourable circumstances permit, the study of the fundamental causes which produce the phenomena, their magnitude and their mode of operation—and the anticipation with some approximation at least, of their effects in those regions where observation has not yet penetrated. It is at least well to keep in mind this higher object, and to endeavour to prepare the way for it, even though the great imperfection of the data may render its attainment impossible at present.'

Gauss in his great memoir applied the theory of potential to the earth's magnetic field and developed the method of spherical harmonic analysis to analyze the permanent field of the earth.

What we observe experimentally is the distribution of the intensity of the magnetic field on the surface of the earth and changes in its distribution with time. From these results of observation, the origin of earth's magnetism and its changes has to be deduced. Gauss worked out a method by which definite information can be obtained regarding the location of the sources. This depends on the analysis of the auxiliary quantity —namely, the potential—from which the several components of the intensity of the earth's field can be derived, not only at the surface of the earth, but also at different positions above and below the surface. The distribution of potential on the surface of the earth can be determined from observations of horizontal force alone. A knowledge of the vertical force is not necessary for this. Gauss showed how the potential can be expanded in a double series of spherical harmonics. One of these series is due to causes within the earth and the other to causes outside. The potential due to internal sources has terms proportional to

a^2/r^2, a^3/r^3, a^4/r^4, etc. while that due to external ones has terms proportional to r/a, r^2/a^2, r^3/a^3, etc. By making use of the additional knowledge of the distribution of the vertical force, it is possible to separate the internal from the external parts of the potential.

Assuming that the magnetic matter was situated within the body of the earth, and using the data of magnetic field at a few places, Gauss calculated the distribution of permanent field over the surface of the earth and obtained a fair agreement between the calculated and observed distributions. Discussing the assumptions, Gauss remarks: 'Another part of our theory on which there may exist a doubt is the supposition that the agents of the terrestrial magnetic force are situated exclusively in the interior of the earth. If we seek for their immediate causes, partly or wholly, without the earth, and confine ourselves to known scientific grounds, we can only think of galvanic currents. But the atmosphere is no conductor of such currents, neither is vacant space; thus in seeking in the upper regions for a vehicle of galvanic currents we go beyond our knowledge. But our ignorance gives us no right absolutely to deny the possibility of such currents; we are forbidden to do so by the enigmatical phenomenon of the Aurora Borealis, in which there is every appearance that electricity in motion performs a principal part. It will therefore still be interesting to examine what form magnetic action arising from such currents would assume on the surface of the earth.' While showing that the cause of the permanent field of the earth should be definitely located within the earth, Gauss did not overlook the possibility 'of a part, though comparatively very small part, of the terrestrial magnetic force, proceeding from the upper regions'.

He also pointed out that the variations of magnetic force taking place simultaneously at different places on the earth's surface can be subjected to a perfectly similar treatment.

Before we pass on to a consideration of the changing part of the earth's field, it is useful to summarize some of the salient features of the 'permanent' or quasi-permanent magnetic field of the earth as they are known at present. This consists of a homogeneous or 'regular' part and an 'irregular' part, the former being due to terms of the first order in the series development for the potential. The regular field is the same as that due to a uniformly magnetized sphere of the same size as the earth, the intensity of magnetization being ·074 (about 1/5500 of the remanent magnetism of cobalt steel) and the total magnetic moment $8{\cdot}4\times10^{25}$ C.G.S. units. The axis of magnetization cuts the earth's surface at 78½°N., 69°W. and 78½°S., 249°W. and is thus inclined 11½° to the earth's axis of rotation. The analysis of the irregular or 'residual' part of the field shows that the average equivalent intensity of magnetization is greater for those latitudes in which land predominates.

The earth's total field is made up of a part due to an internal potential system which accounts for 94 per cent. and an external and a non-potential system which accounts for the remainder.

From the analysis of the earth's field carried out at different epochs from 1842 to 1922, it is known that the magnetic moment of the earth has decreased from $0{\cdot}328/a^3$ in 1842 to $0{\cdot}324/a^3$ in 1885 and $0{\cdot}311/a^3$ in 1922, the average *annual* rate of decrease in the intensity of magnetization during 80 years being $\frac{1}{1500}$ of its value. Therefore, in addition to the well-known secular change in the direction of the earth's magnetic axis, a slow demagnetization of the earth is also going on. Whether this will continue or reverse its direction after some time is more than we can say at present. Regarding secular variation, Maxwell says: 'What cause, whether exterior to the earth or in its inner depths, produces such enormous changes in the earth's magnetism, that its magnetic poles move slowly from one part of the globe to another? When we consider that the intensity of the magnetization of the great globe of the earth is quite comparable with that which we produce with much difficulty in our steel magnets, these immense changes in so large a body force us to conclude that we are not yet acquainted with one of the most powerful agents in nature, the scene of whose activity lies in those inner depths of the earth, to the knowledge of which we have so few means of access.' Although seismology has given us new insight into the internal structure of the earth and the study of magnetic daily variations and variations associated with magnetic storms has definitely added to our knowledge of the conductivity of the earth's interior, the position as regards the fundamental problem of the origin of the earth's permanent magnetic field has not appreciably advanced since Maxwell wrote.

Besides the slow secular variation there are many other variations, some regular and others irregular, to which the earth's magnetic field is subject. The principal regular variations are the solar and lunar diurnal variations and their changes with season and solar activity, the annual variation and the eleven-year variation. The irregular variations or disturbances are of many classes, the most conspicuous of them being the world-wide 'magnetic storms'. The disturbances also have quasi-periodicities depending on (1) the rotation of the sun, (2) the inclination of the earth's magnetic axis to its axis of rotation, and (3) the sunspot cycle. The study of the geomagnetic *variations* and of associated phenomena such as the auroræ has given valuable knowledge about the electrical properties of the earth's atmosphere.

The Solar diurnal variations of the earth's magnetic field and their analysis.

The solar diurnal variation is the most obvious and the most important of the periodic variations of the earth's magnetic

field. At places on the same latitude, the variation depends mainly on the local time (owing to the non-coincidence of the magnetic and rotational axes of the earth and local variations of the earth's magnetic field, there are, however, small differences in the diurnal variation from place to place in the same latitude). On magnetically quiet days, the daily variation is much greater when the sun is above the horizon than when it is below; it is greater in summer than in winter and increases with increase of sunspot frequency. The variation shows large changes as we go from the equator to the pole.

How the sun causes the daily variations in the magnetism of the earth was discussed by Balfour Stewart[2] in a famous article in the ninth edition of the Encyclopædia Britannica. He surmised that the upper regions of the atmosphere were most probably the seat of solar influence with electric currents circulating in them and did not consider as serious what was then considered as an objection, viz., that the conductivity of ordinary air was too small to sustain currents. He also pointed out that a system of currents in the upper atmosphere would exert an indirect effect on the magnetic needle by inducing currents in the body of the earth.

Schuster[3] was the first to investigate the subject in a quantitative manner. The first step in his analysis of variation data was to split up the curve of variation of each of the components into Fourier series. Gauss's method of spherical harmonic analysis was then applied to the Fourier coefficients of

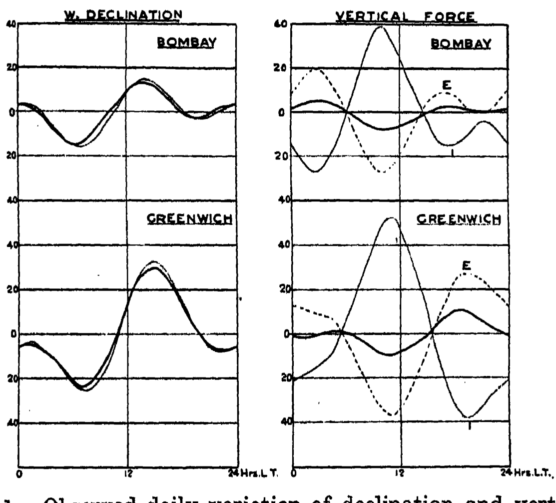


FIG. 1. Observed daily variation of declination and vertical force at Bombay and Greenwich (———) compared with values calculated on the assumption that the origin of the daily variations is (1) inside the earth (———) and (2) external to the earth (..........).

variation at four observatories—Bombay, Lisbon, Greenwich and St. Petersburg. He showed that the horizontal variation field could be represented by a surface harmonic but in order to explain the vertical variations as well, it was necessary to assume that the main source of disturbance lay outside the earth and that in addition to the external source, there was an internal source standing in fixed relationship to the external. In Fig. 1 are shown the observed variations of H at Bombay and Greenwich together with the variations calculated from the spherical harmonic expansion for the potential. On the right-hand side of the same figure are shown the observed variations of Z and the variations calculated from the potential distribution assuming that the source was (1) entirely outside the earth's surface and (2) entirely within the earth's surface. It is obvious that the main source has to be considered as lying outside the earth's surface.

A more complete analysis of the solar diurnal variation field using the data of 21 observatories was carried out by Chapman.[4] The results of the analysis are best expressed in the form of a diagram showing the system of electric currents in the upper atmosphere that could cause the observed field.

At the time of the equinoxes, the current system consists of four closed circuits, two lying on each side of the equator. Of the two circuits in each hemisphere, the one lying in the sunlit part of the earth is the more intense and the direction of the current is clockwise in the northern hemisphere with its focus at about 40°N. At the time of the solstices, the current system is more intense in the summer hemisphere and extends across the equator to the other hemisphere.

As the diurnal variation at the time of the equinoxes is symmetrical about the equator and as the vertical component of the variation field changes sign on crossing the equator, Schuster suggested that the electric currents are caused by horizontal oscillatory movements of the conducting upper atmosphere, rendered conducting by the ionizing action of solar ultra-violet radiation, across the vertical lines of force of the earth's field. The magnitude of the electromotive forces generated by such movements would depend on the velocity of movement and the vertical intensity. The current densities will of course depend also on the conductivity of the atmospheric layer which undergoes the oscillatory movement. The total flow of current in the day time circuit varies from 6×10^4 amperes at the time of the equinoxes to 9×10^4 in summer.

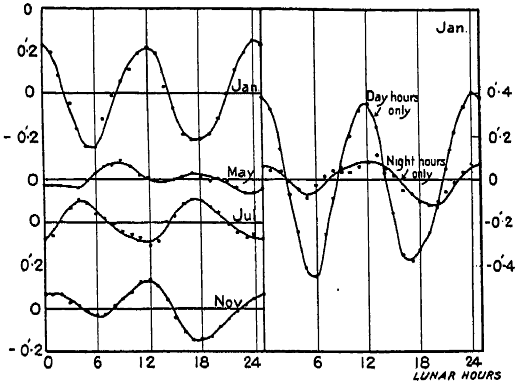
The Lunar diurnal variation field.

Before we go into the details of the oscillatory movement in the upper atmosphere, we shall consider an even simpler, though less obvious, variation field, namely that of lunar diurnal

variation. Its mean magnitude at the equator is only about $\frac{1}{15}$ of that of the solar variation. When averaged over a large number of complete lunations, the curve of variation is a simple semi-diurnal sine wave. But in any particular phase of the moon, the amplitude is considerably enhanced during the daylight hours of the day. This was recognized as early as 1874 by Mr. Alan Broun [5] in his discussion of the observations of magnetic

FIG. 2.

MEAN LUNAR DIURNAL VARIATION OF DECLINATION AT TRIVANDRUM FROM A. BROUN'S ANALYSIS.



declination at Trivandrum (Fig. 2). It is very well brought out in Moos's analysis of the lunar diurnal variation at Bombay in different phases of the moon. The external current systems required to produce the lunar diurnal variation at the times of equinoctial and summer new moons have been shown in diagrams by Chapman.

There is little doubt that the lunar semi-diurnal wave is due to the tidal action of the moon on an atmosphere of varying conductivity.

In both solar and lunar diurnal variation fields, the external part is 2 to 2·5 times the internal and the phase of each of the first four harmonic components of the internal field is in advance of the corresponding components of the external field by about 20°. This is the evidence for believing that the internal field is an induction effect of the external primary field. The electromotive forces induced in a conducting sphere by currents circulating in an outer shell have been investigated by H. Lamb. In order to explain the relative phases and amplitudes of the external and internal fields, it is necessary to assume that the conductivity of the earth is non-uniform and that the crust of the earth down to a depth of about 240 km. has much smaller conductivity than the inside. We shall not, however, pursue this part of the subject further.

Cause of the upper atmospheric current system and its location in the atmosphere.

In explaining the upper atmospheric current system, there are two distinct questions to be answered. What is the cause of the atmospheric movement and how is the conductivity produced?

The answer to these questions has been attempted in the most comprehensive way in the 'dynomo' theory of diurnal variations. Schuster tried to connect the atmospheric movement with the well-known diurnal variation of atmospheric pressure. The most important term in the daily oscillation of pressure is the semi-diurnal term. This is a wandering pressure-wave moving from east to west with a free period of 12 hrs. together with a stationary wave from north to south with nodal lines at $\pm 35°$ latitude. The magnitude of the semi-diurnal wave, according to Simpson, is given by the equation

$$0{\cdot}937 \sin^3\theta \sin(2t+154°)+0{\cdot}137(\cos^2\theta-\tfrac{1}{3})\sin(2t-2\phi+105°)$$

where θ is the co-latitude, ϕ is the longitude east of Greenwich, and the unit of pressure is 1 mm. of mercury. The relation between wind and pressure variation, in which the deviating force of the earth's rotation is neglected, is

$$(\tfrac{1}{2}v^2)\,(d\psi/dt) = -\delta p/p,$$

where ψ is the velocity-potential, $d\psi/ds$ the velocity in the direction ds and v is the velocity of sound. The velocity-field corresponding to the moving pressure-wave shows maximum easterly winds at 9-10 hrs. and maximum westerly winds at 15-16 hrs. local time. The calculated and observed values of the semi-diurnal components of velocity at St. Helena are given below:

Semi-diurnal winds at St. Helena.

	Observed.	*Calculated from pressure variation.*
West to East ..	$-22\sin(2nt+158°)$	$-21\sin(2nt+154°)$
North to South ..	$35\sin(2nt+237°)$	$9\sin(2nt+244°)$

The unit of velocity is 1 cm./sec. While the phases of the wind and the amplitudes of the west to east component agree, the observed north to south component is much stronger than the calculated.

The amplitude of the lunar semi-diurnal pressure tide at the equator is only about $\frac{1}{16}$ of the solar tide.

If the oscillations in the upper atmosphere causing the magnetic variations are directly related to the barometric variations observed at ground level, there should be agreement as regards phase between the two variations. Let us now compare them:

Cause of variation.	Observed pressure variation at ground level	Observed magnetic variation.	Pressure variation calculated from magnetic variation.	Col. (4) corrected for phase change due to self-induction.
Solar ..	sin $(2t-206°)$	sin $(2t-65°)$	sin $(2t-155°)$	sin $(2t-115°)$
Lunar ..	sin $(2t-295°)$	sin $(2t-12°)$	sin $(2t-102°)$	sin $(2t-62°)$

There is thus a difference of phase between the observed pressure variation at the ground and the upper atmospheric pressure variation calculated from magnetic data. The calculated value exceeds the observed by 91° in the case of solar and by 233° in the case of lunar variation.

The probable solution of this difficulty as well as of a cognate difficulty regarding the conductivity of the upper atmosphere has been recently offered by C. L. Pekeris.[6] The question of the origin of the solar semi-diurnal wave of pressure itself has long been a puzzle. Analysis of the pressure curves of many stations leaves no doubt that the semi-diurnal wave is more fundamental than the diurnal. We know that there is an external periodic force acting on the atmosphere in the shape of daily insolation. But it is not the 24-hourly pressure-wave that has the largest amplitude in the barograms but the 12-hourly. The magnitude of the 12-hourly wave can be explained, as was suggested by Lord Kelvin, if the atmosphere had a free period in the close neighbourhood of 12 hrs. From the spreading of the air-waves from the volcanic eruption at Krakatau, it has long been known that the atmosphere has a free period of about 10½ hrs. and G. I. Taylor showed theoretically that the atmosphere has a free mode of oscillation of this period. An assumption in Taylor's calculation of the free period was that the stratosphere was isothermal. Now, various lines of evidence, such as the propagation of sound waves from explosions, the existence of ozone in the upper atmosphere, etc. have shown that there is an increase of temperature in the stratosphere above 35 km. Pekeris, assuming that this increase of temperature continues up to about 60 km. (temperature 370°*K*), beyond which it again decreases, reaching 220°*K* at 100 km., shows that there are two possible modes of oscillation, one with a period 10½ hrs. and another with a period 12 hrs. The 12-hourly oscillation has a nodal surface at 30 km. and the atmospheres above and below this level oscillate horizontally in opposite directions. The amplitude of the 12-hourly wave at 100 km. is nearly 200 times that at the ground. The work of Pekeris removes to some extent the difficulties of the dynomo theory of the diurnal variation of the earth's magnetic field.

While on the subject of pressure waves in the upper atmosphere, I may refer to the recent announcement of E. V. Appleton and K. Weekes in *Nature* on the discovery of a lunar semi-diurnal wave in the height of the E layer over England. Making use of a series of quarter-hourly observations extending over a period of eight months, and suitably eliminating the effect of solar diurnal and seasonal variations of height, Appleton and Weekes have found evidence for the existence of a lunar semi-diurnal wave with a pressure range $\delta p/p$ of ·068 at 110 km., which comes to nearly 6,000 times the lunar barometric range at ground level. The maximum height of the lunar tide is found to occur at about 20 mts. before the upper and lower culminations of moon respectively. The magnitude of the oscillation is 1·5 to 2 km. A large discrepancy appears in that the phase of the upper atmospheric tide is found to be nearly the same as that at ground level at Greenwich, a conclusion which is in *disagreement* with deductions made from the lunar magnetic variations assuming such currents to flow in region E. The amplitude of the tide is also much larger than that calculated by Pekeris.

The conductivity of the upper atmospheric layers responsible for the solar diurnal variation.

The currents in the upper atmosphere depend on the conductivity at the levels concerned. The fact that the range of magnetic variation is much larger during day than during night both for solar and lunar variations can be most simply explained on the assumption that the conductivity is not constant but varies during the day. Assuming that the electric currents responsible for the diurnal variations lie in a spherical shell concentric with the earth, Chapman showed that the relative proportion of the various harmonics can be satisfactorily explained if the conductivity is assumed to be of the form $1+3\cos Z+\frac{9}{4}\cos^2 Z$, where Z is the zenith distance of the sun. If the velocities of oscillatory movement in the upper atmosphere are the same as those calculated from the surface barometric variation, the total conductivity $\int \sigma dh$ of the conducting layer just beneath the sun comes to $1{\cdot}1\times 10^{16}$ e.s. units in minimum sunspot years and $1{\cdot}8\times 10^{16}$ in maximum sunspot years. If the effect of self-induction is taken into account, the maximum conductivity will be increased to $2{\cdot}3\times 10^{16}$ e.s. units. If this conductivity is uniformly distributed over a thickness of 50 km., the mean specific conductivity will be $4{\cdot}5\times 10^{8}$ e.s. units or 5×10^{-3} ohm^{-1} cm^{-1}. This may be compared with the specific conductivity of sea-water which is 4×10^{-2} ohm^{-1} cm^{-2}.

The level of the solar diurnal variation layer.

The question of the level of the atmospheric layer in which the magnetic diurnal variations arise is one of great interest.

We know that maxima of electron concentration occur at about 100 km. in the E layer and at about 270 km. in the F layer. Besides, there is a D layer with a variable and smaller electron concentration at 50–60 km. A lower F_1 layer separates out from the main F_2 layer during day and rejoins it at night.

A comparison of the curves of variation of the ionization of different regions with the time of day, season and sunspot frequency suggests that the diurnal variation currents flow in or near the E region of the atmosphere.

The conductivity of any region of the upper atmosphere can be estimated from ionospheric data. In doing this, a few complicating circumstances have to be kept in mind. In a magnetic field, the conductivity of an ionized gas is not isotropic but is smaller in a direction transverse to the field than in one parallel to it, in the ratio $\nu^2/(\nu^2+\rho^2_H)$, where ν is the collision frequency of the charged particles and $\rho_H = He/2mc$. In high magnetic latitudes where the vertical component of the field is large, and also in low magnetic latitudes for east to west direction, it is the transverse conductivity that will decide the magnitude of the currents. Moreover, both electrons and ions can contribute to the conductivity. To make a correct estimate of the total conductivity of a region, we have therefore to know the law of distribution of ions and electrons with height. The question has been recently discussed in a thorough manner by Appleton[7] in his Bakerian Lecture 'Regularities and Irregularities in the Ionosphere'. He finds that the total direct current conductivity $\int \sigma dh$ of the E region for horizontal electromotive forces is about $2{\cdot}3\times 10^{11}$ e.s. units if we assume that the conductivity is due to electrons, the maximum density of electrons being $1{\cdot}5\times 10^{5}$/c.c. and their collision frequency at that level 10^{5}/sec. If on the other hand, it is assumed that the conductivity is due to ions of mass, say 28, and the corresponding collision frequency is 10^{3}, the total conductivity for the same number of ions comes out to be 4×10^{12} e.s. units. At a low pressure and in a magnetic field, the ionic conductivity can thus be more important than the electronic conductivity.

As an ionized region absorbs the energy of high frequency waves passing through it and the absorption is related to the conductivity, the total direct-current conductivity of the atmospheric layers below the F region can also be estimated from the reflection coefficients of waves penetrating the E layer but reflected back to earth from F. The total conductivity calculated in this manner for summer noon over England comes to be of the order 10^{11} e.s.u., assuming the absorption to be due to electrons.

As we have already seen, the D.C. conductivity demanded by magnetic diurnal variations is of the order 10^{16} e.s.u., if we assume that the oscillatory movements in the upper air are

the same as those calculated from the barometric variations at ground-level. With Pekeris' correction the conductivity required will become 200 times smaller. Even then, it would be larger than that calculated from ionospheric data. This difficulty has been to a large extent removed by Massey's[8] recent work on atomic processes in the upper atmosphere in which he has shown that the rate of recombination of electrons in the *E* layer is much slower than that of either attachment or detachment and that an equilibrium ratio of 100 : 1 will be set up in that region in a few minutes between the negative ions and electrons. With a density of ions of 10^{7}/c.c. at 100 km., the contribution to the conductivity will come mainly from the ions and will be sufficient to explain the high value required by magnetic data.

In spite of its drawbacks, the 'dynomo' theory of solar and lunar diurnal variation seems to explain observations best. When Chapman first worked it out in detail, there were two main difficulties: one was that the phase of the magnetic variations did not agree with that deduced from the barometric variations at ground level and the second was that the electric conductivity demanded was much larger than that deduced from radio data. The first objection was reduced in importance by Pekeris' work on tidal oscillations in a two-layered atmosphere in which he showed that the semi-diurnal wave at 100 km. is opposite in phase to that at the ground and the second objection was met partly by Pekeris' showing that the amplitude of the 12 hourly wave at 100 km. is nearly 200 times that at the ground and partly by Massey's work on processes of recombination and attachment in the upper atmosphere wherein he gave reasons for thinking that the density of negative ions in the *E* region may be about 100 times that of electrons in the same region.

It may also be mentioned that owing to the increase of molecular conductivity at higher levels, the damping of tidal oscillations by conduction and viscosity will be negligible at 100 km. and will be very large at 200 km.

Diamagnetic and drift-current theories of solar diurnal variation.

Two other theories of solar diurnal variation have been proposed, a diamagnetic theory of the upper atmosphere by Ross Gunn and a drift-current theory by Chapman. According to the former, in the upper levels of the atmosphere where the time between two collisions of a charged particle is long compared with the time for a rotation of the particle round the lines of magnetic force, the particle will rotate round the lines of force in such a direction as to render the layers diamagnetic, the susceptibility depending on the density of electrons and ions and on their speeds. Assuming a suitable variation of charge

density with local time, qualitative agreement with the observed field variation can be obtained, but the calculated field is too small unless temperatures of the order of 1000°C are assumed for the long free path region. According to the drift-current theory, in the region of long free paths, the charged particles fall freely under gravity and their motion being inclined to the direction of the magnetic field, they are deflected in a horizontal direction, giving rise to an eastward current over the equatorial regions. Owing to the diurnal variation of ionization, the currents will not remain parallel to the latitudes throughout the day but will diverge and converge giving rise to the observed variation of field. The theory has not been worked out in a quantitative form.

Both these theories place the seat of solar diurnal variation in the long free path region.

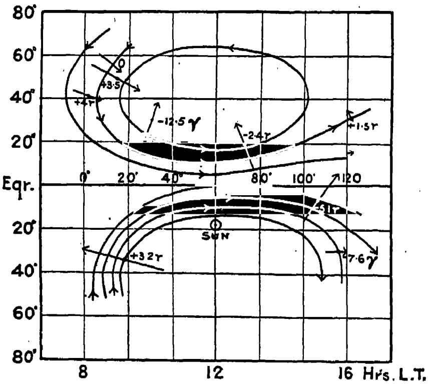
Evidence from magnetic disturbances associated with radio fade-outs.

Within the last four years, fresh evidence has appeared regarding the location of the currents responsible for the solar diurnal variations. This comes from an analysis of the magnetic disturbances accompanying radio fade-outs. In long distance short-wave radio transmission, it was noticed that occasionally the signals entirely disappeared quite suddenly and made their reappearance after a period ranging from 15 to 45 minutes. Detailed investigation by M. Jouaust of France showed that these fade-outs occurred simultaneously over different parts of the earth. J. H. Dellinger [9] of the American Bureau of Standards working in collaboration with the workers of the Mount Wilson Solar Observatory discovered that when the radio fade-outs occurred, there was a simultaneous appearance of a bright eruption on some small portion of the sun's surface (usually in the neighbourhood of a sunspot) and as the brightness of the solar eruption waned, the radio signals gradually regained their strength. It was also noticed that during the time of the solar eruptions, there appeared in the traces of self-recording magnetographs a characteristic sudden disturbance, a phenomenon which had been noticed as early as 1859 and remarked on by Balfour Stewart. To understand the character of the changes in the ionosphere responsible for these disturbances, it is necessary to study the distribution of the changes of the directions and magnitude of the magnetic field over the surface of the earth. This was done by A. G. McNish[10] for the western hemisphere. In 1936, the magnetograms of the Alibag Observatory showed 16 clear instances of such disturbances. On enquiry the Engineers of the Indian Radio and Cables Co., Ltd., supplied a list of the times of occurrence of the radio fade-outs which had been observed in India during the communication of signals between

India and England and India and Japan. On all such occasions, marked disturbances in the magnetic curves had occurred. In

FIG. 3.

ELECTRIC CURRENTS IN THE UPPER ATMOSPHERE ASSOCIATED WITH THE RADIO FADE-OUT OF 26TH. JAN. 1937—BEGINNING 7h. 57m. G.M.T.



The arrows show the directions and magnitudes of the changes in the horizontal field and the figures the changes in the vertical field, positive sign indicating increase in downward component.

Fig. 3 are plotted the changes of magnetic field due to one such disturbance which occurred on January 26, 1937.* The important point to notice is that if we assume the disturbance to be due to a system of electric currents in the upper atmosphere, it is nearly of the same form and position as the system of currents required to explain the solar diurnal variations of the earth's field. This suggests that the effect of the solar outburst is to produce an increase in the ionization and hence the conductivity in and near the levels at which the ordinary quiet-day variations take place.

Progress in ionospheric technique has provided means of locating the approximate level at which a sudden burst of ionization is caused by the solar eruption. During a radio fade-out, the initial cut-off of reflected waves from the ionosphere is abrupt from all the layers E, F_1 and F_2, but the waves reflected from the lower layers disappear a little earlier. The reappearance of the signals is distinctly earlier from F_2 than from F_1, from F_1 than from E and so on. When the signals have reappeared the charge-densities of F_2 and F_1 show practically no change, while the charge-density of E shows a slight increase. These facts

*I am indebted to the Directors of the respective observatories for kindly sending me their original magnetograms or their copies from which this and similar charts have been prepared.

and the rapidity with which normal conditions are restored make it certain that the ionization due to the solar flare takes place in and below the E layer. The current system due to the fade-out being similar to the solar diurnal variation makes us infer that the latter also is located in or near the E layer.

Magnetic storms.

Besides the periodic variations of the earth's magnetic field, there are irregular variations of different kinds. Some of them are of well-defined types. The most important of them is the 'magnetic storm'. In our latitudes, a 'world-wide' magnetic storm may cause changes of horizontal intensity amounting to 800 γ, or more than one-fifth the normal value of

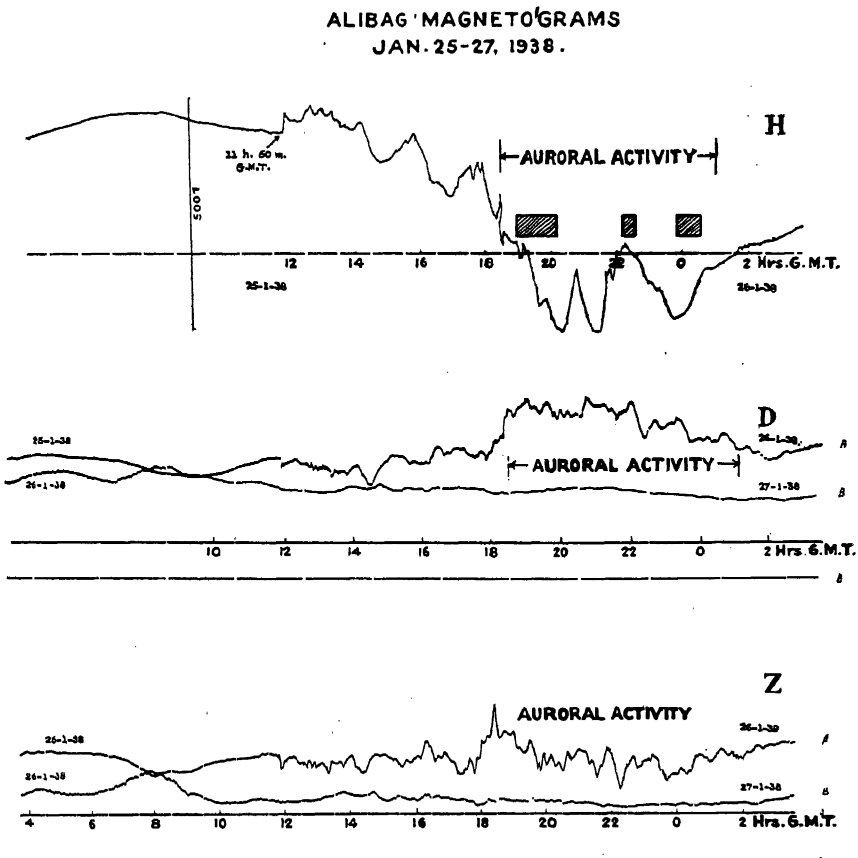


FIG. 4.

the field. The characteristic features of magnetic storms have been analyzed by Moos,[11] Chapman[12] and others. Moos made a detailed analysis of Bombay data and Chapman extended and amplified it including data from other parts of the earth. The time-variation of the magnetic elements after the onset of a storm depends to an appreciable extent on the time of the day. It can be analyzed into (1) a storm-time variation and (2) a local time variation. The local time variation consists of a diurnal oscillation, with maximum departures from normal in M and Z, the horizontal and vertical components of the field, at about 6 hrs. and 18 hrs.

Magnetic storms often begin with an impulsive change in H—generally an increase—followed by oscillations. Within an hour or two after this 'sudden commencement', follows a period of rapidly diminishing H, lasting for 6 to 12 hrs. The period of abnormally low values of H is the second or *main phase*. Finally, there is a gradual return of conditions to normal, which may go on for three or four days. (Fig. 4.)

Both the 'sudden commencement' as well as the maximum change of field during the main phase of the storm show systematic geographical distributions. The 'sudden commencement' —which is most marked in H—is generally a maximum near the equator and decreases towards the poles. Sometimes, there is an increase of intensity in the neighbourhood of the auroral zone. The maximum disturbance during the main phase also shows a decrease in the same direction, but after 60°– 65° geomagnetic latitude, the disturbance sharply rises to a maximum in all the elements. The more intense the storm, the lower is the latitude at which the sharp increase in disturbance takes place. The storm-time variations can be analyzed in a manner similar to the diurnal variations by the method of spherical harmonic analysis in order to ascertain whether the source is internal or external. The result of such a study has been to show that the main source of disturbance lies outside the earth with an internal induced system associated with it. That the outside source is a system of electric currents either in the earth's atmosphere or outside it, was the view put forward by Birkeland[13] in his classical discussion of the magnetic results of the Norwegian Aurora Polaris Expedition of 1902-03. It is desirable to consider the current systems associated with the preliminary phase and the main phase of the storm separately.

(*a*) *Preliminary phase.*

The disturbance vector is directed northward in low and middle latitudes and the sudden commencement occurs within two minutes all over the earth, on the dark side as well as the bright side. The impetus is a maximum over the equator, and there is sometimes, but not always, another maximum near the

auroral zone. The current system required is an eastward flow all round the earth, and corresponds to the 'positive equatorial perturbation' of Birkeland.

Main phase.

The current system due to the main phase has been studied by Chapman [14] and his co-workers and by Goldie.[15] The system can be divided into two parts corresponding to the storm-time and the local time variations of the disturbance field. These consist of (1) a westward flow with a diffuse maximum of current density over the equator and a concentrated maximum over the auroral zone and (2) a system of four vortices, two in the northern and two in the southern hemisphere. The direction of the forenoon vortices is cyclonic and of the afternoon ones anticyclonic. The afternoon vortices are generally the more intense. The combined and component current systems (assuming them to lie in a thin spherical shell surrounding the earth) are shown in diagrams by Chapman. In the maximum storm-time phase of moderate storms, a total current of the order of 5×10^5 amperes, flows westward in extra-auroral regions and currents of the order of $3{\cdot}5 \times 10^5$ and 2×10^5 amperes flow westward and eastward respectively in the auroral zone. In very great storms, the current density may exceed ten times this amount. Chapman's scheme of electric current systems may be compared with those worked out for individual disturbances by Birkeland and for the average of 10 storms by Goldie.

Location of the currents.

There is little doubt that during the main phase of the storm, the currents *in the auroral zone* lie mainly in the earth's atmosphere. The connection between auroræ and magnetic storms is very close, great magnetic storms being associated with marked southerly movement of the auroral region (see Vestine's diagram showing average directions of magnetic disturbance vectors and of auroral arcs). The most frequent height of auroræ is in the neighbourhood of 110 km. Birkeland, from his calculations of the spatial variation of the field near the auroral region found that the heights of the currents lay between 150 and 600 km. Goldie estimated the mean heights of the currents to be 290 km. at 2 hrs. local time and 370 km. at 17 hrs. McNish[16] and Vestine in recent analysis of the heights of electric current systems due to 'polar elementary storms' and smaller disturbances have taken into account the effect of the induced field inside the earth and found that the hypothesis that fits the facts best is a current at 100–150 km., a region where the direct current conductivity of the upper atmosphere is a maximum. The probability therefore is that the concentration of magnetic field in the

auroral zone during the main phase of magnetic storms is also due to a concentrated current system round the geomagnetic pole at a height of 100–150 km. above the earth flowing along auroral paths of large conductivity.

The location of the current system causing an 'equatorial perturbation' is more difficult. Various reasons make it necessary to place it well outside the earth's atmosphere. The magnetic changes are greatest in regions round the equator and the disturbing vector is directed similarly in both the northern and southern hemispheres. The facts of magnetism can be most simply explained by assuming, with Birkeland, that it is due to a ring-current round the earth with maximum intensity over the equator, the size of the ring being comparable with the diameter of the earth. The direction of the ring-current would be eastward at the time of 'the sudden commencement' and westward during the main phase of the storm. That the formation of such ring-currents is possible when a stream of charged particles flows towards a magnetized sphere was demonstrated by the laboratory experiments of Birkeland and the calculations of Störmer.[17]

An attempt at finding the position of the equatorial ring-currents has been recently made by S. E. Forbush[18] in the case of two magnetic storms, one of which began on August 21, 1936 and another on January 16, 1938. The storm-time variations of the earth's field were analyzed, assuming them to be due to (1) a westward ring-current over the geomagnetic equator and (2) two concentrated westward current systems over the north and south auroral zones, at a height of 150 km. above ground and (3) the associated induced fields. The result of the analysis as regards the position of the equatorial ring-current is shown in the following table:—

Estimated value R/a of equatorial ring-current.

Date of commencement of storm.	Time after commencement.	Estimated zonal current and polar distance.	R/a
Aug. 21, 1937	30–78 hrs.	4×10^4 amp. and 20°	4·0
	54 hrs. (adjusted by smoothing)	do.	2·5
Jan. 16, 1938	22–46 hrs. } 54–78 hrs. }	$6{\cdot}2\times 10^4$ and 28°	15·8
	54 hrs. (smoothed)	do.	2·1
Disturbed days minus quiet days.		2×10^4	2·3

In the case of storms, the radius of the ring-current is not less than two earth-radii, but may greatly exceed that figure. For a mean disturbed day, the radius is of the order of 2 to 3 earth-radii.

A line of study which in the near future is likely to yield valuable information regarding these ring-currents is the effect of magnetic storms on cosmic ray intensity. That there was a decrease in cosmic ray intensity throughout the earth from the equator to 50°N. during a magnetic storm was noticed by a number of cosmic ray investigators during the magnetic storm of April 26, 1937. Usually, a fall of horizontal intensity is associated with a decrease of cosmic ray intensity. It was pointed out by Chapman that this effect was probably due to the postulated ring currents and that the change in cosmic ray intensity might enable us to determine the height of the currents above the earth. While for the same storm, the changes in H and changes in cosmic ray intensity seem to be correlated, the mean ratio $\Delta J/\Delta H$ for different storms are different. For instance, in the storm commencing on August 21, 1937, there was hardly any effect on the cosmic ray intensity. This can be explained if the current systems for different storms flow at different distances. The calculated values of the radii of the equatorial current system calculated from the changes of cosmic ray intensity in three or four magnetic storms are 3 to 4 earth-radii.

A serious difficulty, however, remains. In the above calculations, it is assumed that the effect of the external current system is to increase the magnetic field outside the system and hence to decrease the number of cosmic ray particles reaching low and moderate latitudes. While this is of course true, there will be a corresponding decrease of field between the earth and the external current system and since the largest deflections of the charged particles will occur within this space, the net effect of the ring-current would, *a priori*, be expected to cause an increase in the allowed cone of cosmic rays and hence an *increase* in its intensity. Clay and Bruins[19] think that the only way to escape out of the difficulty is to assume that circular currents normally exist over the equator but that during magnetic storms, they decrease or oscillate. Detailed calculations of the effect of a ring-current on the paths of charged particles are necessary and will no doubt be forthcoming shortly.

Cause of magnetic storms.

The close correlation between magnetic and auroral activity makes it clear that the origins of the two are intimately connected. The corpuscular theory of Birkeland and Störmer explains many of the facts well and in spite of weighty objections to the theory, it appears probable that some modification of it

will survive. A stream of charged particles directed from outside towards a magnetized sphere, such as the earth, will describe a series of orbits determined by the magnetic moment of the sphere and the momentum of the particles. Störmer showed that there exists, about the sphere, a toroidal space with its axis coinciding with that of the sphere, into which the particles will not enter. The equatorial radius of this space is given by $(2^{\frac{1}{2}}-1)\,C$, where $C=(Me/mv)^{\frac{1}{2}}$, M being the magnetic moment of the sphere, and e, m and v the charge, mass and velocity of the particles. C has this physical significance that it is the radius of the equatorial circle which is a possible orbit for the particle. There is thus only a limited region round the magnetic poles to which particles from outside can have entry. The maximum angular extent of this region depends on the momentum of the particles. A table showing the values of C and the maximum angular distance from the poles at which particles can enter the earth's atmosphere, is given below for various kinds of particles.

TABLE.

Nature of particles.	Velocity cm./sec.	$\frac{mv}{e} = H\rho$	C in earth radii.	Angular distance of entry (from magnetic axis).
Cathode rays	$1{\cdot}9\times 10^9$	108	1400	$2^\circ{\cdot}3$
	$9{\cdot}0\times 10^9$	540	660	$3^\circ{\cdot}4$
β rays	$2{\cdot}4\times 10^{10}$	1800	345	$4^\circ{\cdot}6$
	$2{\cdot}8\times 10^{10}$	4500	220	$5^\circ{\cdot}8$
α rays	$1{\cdot}4\times 10^9$	290,000	28	$16^\circ{\cdot}6$
	$2{\cdot}06\times 10^9$	398,000	23	$18^\circ{\cdot}1$
Ca+	$1{\cdot}6\times 10^8$	$6{\cdot}6\times 10^5$	17	20°

Even fast β ray particles with a velocity of $2{\cdot}8\times10^{10}$ cm./sec. cannot get beyond $5^\circ{\cdot}8$ from the magnetic pole. As we know from auroral and magnetic observations that the maximum current densities occur at 20–23° from the poles, the particles, if electrons, must have even greater velocities, or they should be particles of atomic size with momenta exceeding those of the fastest α rays. Milne has calculated that Ca^+ atoms moving away from the sun, would get gradually accelerated owing to absorption of solar radiation from regions outside the centres of the Fraunhofer H and K lines and acquire a maximum velocity of $1{\cdot}6\times10^8$ cm./sec. Such particles will reach the earth in about 28 hrs. and enter the earth at about 20° from the magnetic axis. But their momenta would be too small to penetrate to a depth in

the atmosphere as low as 80–100 km.—which seems to be required by auroral phenomena. Ionospheric studies in the auroral region also point to the conclusion that the particles reach a height of 80–100 km. above ground. Leiv Harang,[20] of the Auroral Observatory at Tromsø in Norway ($\phi=69°40'$N., $\lambda=18°57'$E.) summarizes the general results of radio-echo observations there during magnetic disturbances as follows:—

(1) Momentary formation of a new layer at the level of the E layer during storms.

(2) Formation of an absorbing layer below the usual E layer during the intense phase of the storm causing weakening and sometimes cessation of the echoes on all wave-lengths.

(3) Formation of high F layers during and after the storm with subsequent lowering of height.

(4) Decrease of the critical frequencies of F_1 and F_2.

(5) Rapid changes of $P'f$ curves in periods of magnetic activity.

It has been suggested by Störmer and demonstrated experimentally by Brüche that if there is a ring-current round the earth, its effect would be to shift the position of entry to nearer the equator. If the observed position of the auroral zone is to be explained in this manner, we should expect that the position of maximum disturbance should depend on the strength of the ring-currents, that is, on the strength of the disturbance. It is true that during large disturbances, there is a tendency for the zone of maximum disturbance to shift equatorward, but during

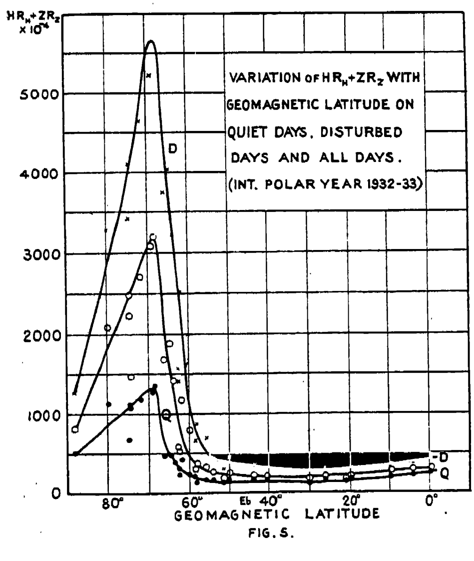


FIG. 5.

weak disturbances, no such tendency seems observable. This may be seen from Fig. 5 in which is shown the variation of disturbance with distance from the magnetic equator on all days, quiet days, and disturbed days prepared from the range data published by the International Commission for Terrestrial Magnetism.

Birkeland and Störmer considered the stream of corpuscles projected from the sun and moving towards the earth as having charges of the same sign. It is now generally agreed that such a stream would not hold together all the way from the sun to the earth without dissipation. Chapman and Ferraro have attempted to work out a detailed theory of magnetic storms and auroræ, assuming the particles to be neutral on the aggregate but composed of equal numbers of positive and negative charges and probably also accompanied by a good number of uncharged particles. Such a composite stream can approach the earth much nearer than a stream of particles all having the same sign; and if a moderate difference in speed between the positive and negative particles is permissible, it is possible for them to form a ring-current round the earth ; but, as Chapman says, 'It must be confessed that we have no clear indication whether or how such a ring could be formed'. However, present-day evidence is tending more and more to the view that an equatorial ring-current is formed outside our atmosphere.

Such a ring-current, when varying, must produce induced currents in our atmosphere; and the question remains to be answered whether we can explain all the effects that we observe in low latitudes during magnetic storms by the effect of the induced currents in a non-uniformly conducting atmosphere. For example, there is the local time variation of magnetic storms. Again, ionospheric workers in moderate latitudes also have found that during magnetic storms, the waves reflected from the F_2 region become weaker, the height of this region increases and its electron density decreases. Observations are obviously needed from low latitudes of the changes that take place in the upper atmosphere during magnetic storms. Some observations perhaps do exist, but they have not become available.

Before leaving the subject, it is desirable to consider briefly a purely atmospheric theory of magnetic storms worked out by Hulbert and Maris.[21] They assume that in times of activity, the sun occasionally emits a sudden blast of ultra-violet radiation lasting for a short period, mainly in the region of wave-lengths below 1500Å. The radiation produces ionization both in the long and short path regions of the sunlit atmosphere. According to them, therefore, the particles do not come from outside; they are produced in our atmosphere mainly in low latitudes. The ionization in the long free path region produces an eastward current and gives rise to the initial phase of the

storm with its increase in H. The ionization in the short free path region increases the conductivity of the atmosphere and causes its expansion; and upward velocity of 10 km./hr. can cause a decrease in H of 100 γ at the equator. The expansion is also supposed to engulf the long free path ions in the rising tide of molecules and convert them into short free path ions. The consequent reduction in the number of long free path ions is believed to be responsible for the observed after-effect of the storm in keeping down the horizontal component of the earth's field below normal for a few days. The most serious objection to the ultra-violet theory is, as pointed out by Chapman, that the ultra-violet theory can account for a velocity of only about 10^6 cm./sec. for the particles by ultra-violet ionization and impact with excited particles and that this velocity is far too small for the particles to penetrate down to 80 km. and explain the various observed features of auroræ.

Conclusion.

From what has been said, it will be clear that the subject of Terrestrial Magnetism presents many problems of great interest both to the experimental and the theoretical physicist. We are still far from the solution of the fundamental problem of the origin of the earth's permanent magnetic field. More information can undoubtedly be gathered about the electrical and magnetic properties of the earth's interior by a study of the magnetic variations on the lines of Chapman and his school. I have not even touched on the application of magnetic methods to the study of the structure of the top layers of the earth's crust—a method which has given results of economic value in other countries and has begun to yield results of great geophysical interest in the hands of the Survey of India. Our knowledge of the exact locations in the earth's interior and in the atmosphere, of the sources of regular and irregular variations of the earth's field is still very incomplete. The question of the existence, permanent or otherwise of a system of ring-currents round the earth is still a matter for discussion.

It has been said that the sun and stars provide us laboratories in which experiments on matter are carried on under conditions of temperatures and pressures which can never be realized in the laboratory. So too our mother Earth provides us a magnet of stupendous dimensions with which various experiments on matter are being continuously carried on and it is for us to observe and collate the results and reason on them so as to know a little more about her and about matter in general.

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TWENTY-SEVENTH INDIAN SCIENCE CONGRESS

MADRAS, 1940

PRESIDENTIAL ADDRESS

Section of Physics

THE DIAMAGNETISM OF THE MOBILE ELECTRONS IN AROMATIC MOLECULES

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SECTION OF PHYSICS

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Presidential Address

THE DIAMAGNETISM OF THE MOBILE ELECTRONS IN AROMATIC MOLECULES

Considerable progress has been made during recent years in our understanding of the structures of aromatic molecules, and in particular of benzene. Much of this progress is due, on the theoretical side, to the application of quantum mechanics to study the nature of the linkage between the carbon atoms in the benzene ring and the part played by the valency electrons in the linkage, and on the experimental side, to the detailed investigations on the Raman and the infra-red spectra of benzene and its deutero-isomers, which have established the symmetry properties of benzene and the nature of its vibrations. One important result that emerges from these structural studies on benzene is that one electron in each carbon atom in the ring is mobile and is more or less free to migrate from atom to atom over the whole of the ring, a result of great significance to the sixty-year-old controversy regarding the location of the extra bonds in the benzene ring.

These mobile electrons have interesting magnetic properties, and I propose in this address to discuss some of these properties. In many respects the magnetic behaviour of these electrons is not dissimilar to that of the free electrons in metals, and the theoretical treatment in the two cases follows nearly the same course. I shall therefore deal first with the properties of free electrons, which are simpler.

The Paramagnetism of an Electron Gas

All the characteristic properties of a metal are explained satisfactorily on the assumption that a certain number of electrons get detached from their atoms and are free to migrate from atom to atom throughout the metal. Taking for example the alkali metals, there is considerable evidence from their optical properties, their Hall coefficients, the fine structure of their emission spectra in the soft X-ray region, theoretical studies on metallic cohesion, etc., to show that the number of such free electrons should be almost exactly one per atom. The para-

magnetic properties of these electrons, regarded as forming a free-electron gas, are easily investigated. In the magnetic field the spin-moments of the electrons will place themselves either parallel or anti-parallel to the field, the number with parallel orientations preponderating, because of their lower energy in the field. Assuming that the preponderance of the parallel spins over the anti-parallel ones is determined by the classical statistics of Boltzmann, the susceptibility per unit volume of the gas will be given by the Curie law

$$\kappa_p = \frac{n\mu^2}{kT}, \qquad \ldots \quad \ldots \quad \ldots \quad (1)$$

where n is the number of electrons per unit volume, μ is the Bohr magneton, and the other letters have their usual significance.

In order, however, that the classical statistics may be applicable, the uncertainty Δq in the location of the position of the electron, which is determined by the Heisenberg relation

$$\Delta q \approx h/\Delta p \approx h/(mkT)^{1/2},$$

should be much less than the average distance between neighbouring electrons in the metal, namely $n^{-1/3}$. This would be the case only at temperatures much higher than

$$T_0 \approx \frac{h^2 n^{2/3}}{mk}.$$

For the alkali metals, with the number of free electrons equal to one per atom, this temperature will be of the order of 10^5 degrees. Hence at all ordinary temperatures the electron gas in these metals will be almost completely degenerate, and the electrons will occupy, in pairs with opposite spins, all the energy levels permitted by Pauli's Exclusion Principle, up to $E \approx kT_0$. A few stray electrons having energies near about kT_0 will occupy their energy levels singly. To put it more precisely, the energy distribution of the electrons will conform to the statistics of Fermi and Dirac.

Now it is only the few stray electrons which occupy their energy levels singly, that can orient in the magnetic field and contribute to the magnetic moment. Their number, n' per unit volume, will obviously be much smaller than n, roughly in the ratio of T to T_0, and the susceptibility will therefore be given by the expression

$$\kappa_p = \frac{n'\mu^2}{kT} \approx \frac{n\mu^2}{kT_0}.$$

This gives the order of magnitude only. Detailed calculation gives for the spin-susceptibility of the degenerate gas

$$\kappa_p = \frac{3}{2}\frac{n\mu^2}{kT_0}, \qquad \ldots \quad \ldots \quad \ldots \quad (2)$$

where T_0, the degeneracy temperature, is given by

$$T_0 = \frac{h^2}{8mk}\left(\frac{3n}{\pi}\right)^{2/3} \quad .. \quad .. \quad .. \quad (3)$$

This in outline is the celebrated explanation given by Pauli for the feeble, temperature-independent paramagnetism exhibited by the alkali metals, which initiated the modern theories of the properties of electrons in metals.

THE DIAMAGNETISM OF A FREE-ELECTRON GAS ON THE CLASSICAL THEORY

That on the pure classical theory a free-electron gas should have no diamagnetism at all, seems to have been first demonstrated by Bohr. This result is at first sight surprising, since in the magnetic field the electrons will all describe paths whose projections on a plane perpendicular to the direction of the field will be circles, and the direction of motion in all the circles will be the same, and such as to give a negative moment along the direction of the field. On more careful consideration, however, it will be seen that the outer electrons in the medium which are too close to the boundary wall to execute complete circles will be reflected repeatedly from the wall, as shown in the diagram, (in which the boundary is assumed to be cylindrical,)

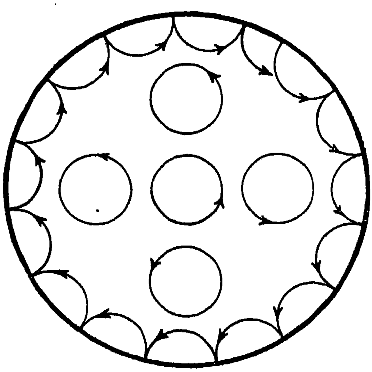


FIG. 1.

and will describe cuspidal paths; obviously this is equivalent to a creeping of these electrons along the boundary wall in a direction opposite to the direction of motion of the inner electrons. Though the creeping will be slow, yet because of the very large orbits in which these electrons creep, their contribution to the magnetic moment will be considerable, and on calculation we

find that it exactly neutralizes the diamagnetic contribution from the inner electrons.

This null result is independent of the nature of the boundary; in fact the boundary may be removed altogether. The result is even more general, and is applicable, as Miss van Leeuwen has demonstrated, not only to an electron gas, but to any dynamical system obeying pure classical statistics. The success of Langevin's apparently classical theory of diamagnetism, which explains so elegantly the diamagnetic properties of atoms and molecules, is due to the initial assumption of well-defined electronic orbits, which is a quantum result.

Landau's Discovery

To Landau we owe the discovery that if the motions of the free electrons in the magnetic field are quantized, as they should be according to our quantum mechanical ideas, the balancing between the diamagnetic moments of the inner electrons which execute uninterrupted paths, and the apparently paramagnetic contributions of the boundary electrons, is disturbed, much in favour of the former, and the result is a large diamagnetic moment. The argument by which the result is deduced is somewhat difficult to appreciate intuitively, and I shall therefore merely quote Landau's result, which has been checked by others, and with other models too. The diamagnetism of the free-electron gas is found to be just one-third of its spin-paramagnetism, whatever the temperature may be, i.e. whether the gas is degenerate or non-degenerate. In other words the diamagnetic susceptibility at high temperatures, $T \gg T_0$, should conform to the Curie law

$$\kappa_d = -\frac{n\mu^2}{3kT}, \qquad \ldots \qquad \ldots \qquad \ldots \qquad (4)$$

and at low temperatures, $T \ll T_0$, when the gas is degenerate, the susceptibility should have the temperature-independent value

$$\kappa_d = -\frac{n\mu^2}{2kT_0}. \qquad \ldots \qquad \ldots \qquad \ldots \qquad (5)$$

The diamagnetism is of course superposed on the spin-paramagnetism, which will predominate, and the resultant susceptibility will be given by

$$\kappa = \kappa_p + \kappa_d.$$

Experimental Verification of Landau's Diamagnetism

It would be of great interest to verify experimentally Landau's result, which is essentially a quantum result and has no counterpart in the classical theory. There are, however, two

serious difficulties in verifying this diamagnetism, firstly the predominant paramagnetism with which it is normally associated, and secondly the enormous degeneracy temperatures for the free electrons in most metals, 10^4 to 10^5 degrees, which render only the degenerate state accessible for experimenting. There is, however, one substance in which, owing to certain special conditions, both these difficulties are eliminated. I mean the crystal of graphite.

Graphite is a hexagonal crystal with a perfect basal cleavage. The carbon atoms in it are arranged in layers parallel to the basal plane, the atoms in each layer forming a regular hexagonal network. The binding between neighbouring layers is extremely loose, and is probably of the van der Waals type, as is evidenced by the very large distance of separation between them, viz. 3·4 A.U., as compared with the distance of 1·42 A.U. between adjacent atoms in the same layer. Three of the electrons in each carbon atom will be utilized in binding it to its three neighbours in the basal plane, and the fourth will be practically free to migrate from atom to atom in the basal plane, much in the same manner as the free electrons in a metal. The probability of the electron jumping to the next layer will be very small.

The conditions obtaining in graphite are very favourable for a verification of the Landau diamagnetism. With a magnetic field incident along the hexagonal axis, we are concerned with the motions of the electrons in the basal plane only, and these motions, as we have seen, are free; the diamagnetic properties of the medium will therefore be those of a free-electron gas. The restriction of the freedom of the electrons practically to the basal plane actually proves to be an advantage; the restriction will be equivalent to an enormously increased effective mass for the electron for motion along the normal to the plane, and as a result the spacing of the energy levels along this direction will become much narrower, and hence the degeneracy temperature much smaller, than for electrons that are free to move in all directions. Lastly, the spin-moments of the electrons in graphite are paired in such a manner as to give zero paramagnetism.

Experimentally, graphite crystal does have an abnormal diamagnetism, which is confined to the direction of the hexagonal axis (the susceptibility in the basal plane being practically the same as that of diamond), and which conforms to the Curie law (4) at high temperatures, and to the temperature-independent value (5) at low temperatures, with the *number of free electrons n equal to one per carbon atom and the degeneracy temperature* $T_0 = 520°K$. At all temperatures (in the range investigated) the susceptibility per carbon atom is found to be the same as the Landau diamagnetism per electron of a free-electron gas having a degeneracy temperature of 520°K. The theoretical values for the specific susceptibility (per gm.) of graphite

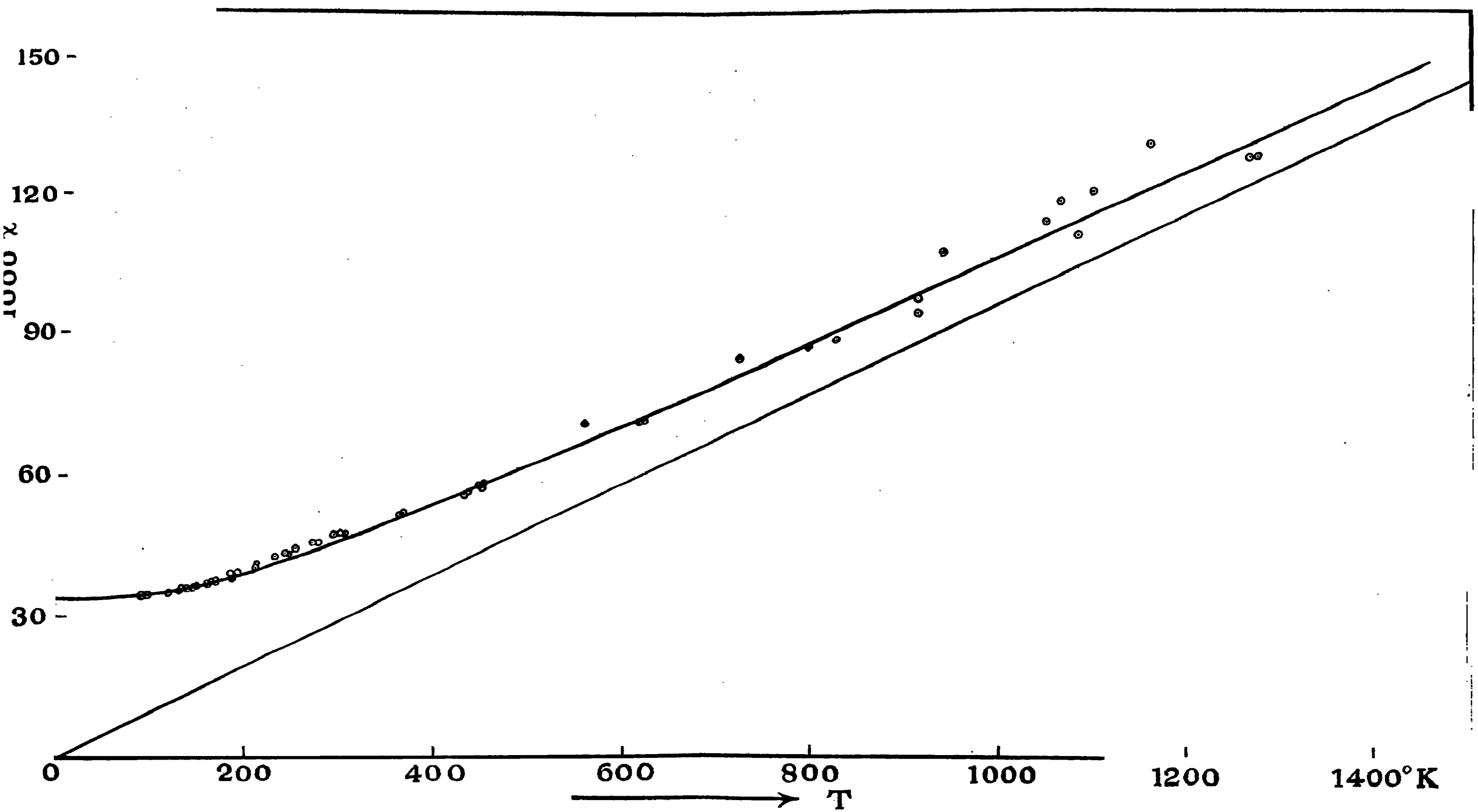


FIG. 2. Temperature variation of the magnetic anisotropy of graphite.

calculated on this basis are represented by the curve drawn in Fig. 2. The straight line which the curve tends to reach asymptotically at high temperatures, namely that corresponding to the Curie law (4), is also drawn in the figure. The circles denote the experimental values obtained by Mr. Ganguli and the present writer, and it will be seen that they all lie close to the theoretical curve.

That one electron per carbon atom should be free to move about in the basal plane agrees, as we have just seen, with the known structure of the crystal. It is further gratifying to find that there is a Brillouin zone which can just accommodate 3 electrons per carbon atom, which is a flat hexagonal prism bounded by $\{000,2\}$ and $\{2\bar{1}\bar{1},0\}$, and the energy-discontinuities across all the faces of the zone are large. There is a bigger zone bounded by $\{000,2\}$ and $\{2\bar{2}0,0\}$ which can just contain all the 4 valency electrons, but the energy-discontinuity across $\{2\bar{2}0,0\}$ is small.

The restriction of the freedom of motion of the metallic electrons in graphite to the basal plane is also evidenced by the enormously greater electrical conductivity of the crystal in the basal plane than along the normal to the plane; the ratio of the two conductivities, according to some recent measurements by Mr. Ganguli and the present writer, is larger than 10^4, probably very much larger.

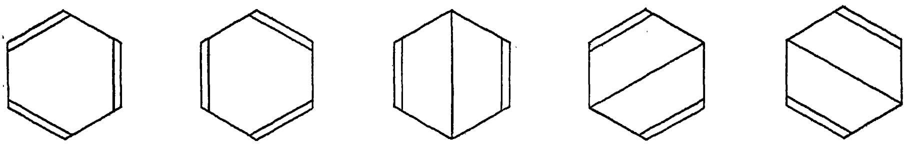
The agreement between the experimental and the theoretical values plotted in Fig. 2 may be regarded as an experimental demonstration of the Landau diamagnetism of a free-electron gas, and of its temperature variation in accordance with the statistics of Fermi and Dirac.

The Mobile Electrons in Aromatic Molecules

Incidentally the magnetic data for graphite lend support to the view that one electron per carbon atom in the crystal is practically free to migrate from atom to atom through the whole layer. Following Lennard-Jones we shall call it the mobile electron, so as to distinguish it from the other three valency electrons in each carbon atom, which are localized and take part in binding it to its three neighbours. The occurrence of such mobile electrons is characteristic of all aromatic molecules—each layer in graphite can be regarded as a single molecule consisting of a very large number of condensed benzene rings—and is an essential feature of the quantum mechanical theories of the structures of these molecules. Their mobility is a necessary consequence of the Uncertainty Principle, according to which the larger the region assigned to these electrons, the smaller would be their kinetic energy. Any localization of these mobile electrons, such as is implied, for example, in the conventional

double-bond (in which a pair of such electrons is involved), will naturally correspond to a very large kinetic energy for these electrons; it is equivalent to restricting the wave-lengths of the standing electron waves to small values of the order of the length of the double-bond, whereas if the electrons are mobile, greater wave-lengths, of the order of the dimensions of the whole molecule, will also be permitted, thus conducing to a lowering of the energy, and to a correspondingly increased stability.

This is essentially the solution offered by quantum mechanics to the old controversy regarding the locations of the extra bonds in the benzene ring: they are not located at all, i.e. they may be anywhere in the ring! If we prefer it, we may, following Pauling and Wheland, express the same result in this form: the actual structure of the benzene ring is that obtained by the 'resonance' between the following five canonical structures,



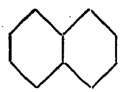
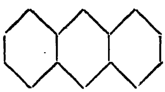
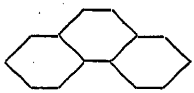
I II III IV V

FIG. 3.

the coefficients to be attached to the wave-functions representing these structures being given by

$$\psi_{\text{benz}} = 0{\cdot}622\,(\psi_{\text{I}} + \psi_{\text{II}}) + 0{\cdot}271\,(\psi_{\text{III}} + \psi_{\text{IV}} + \psi_{\text{V}}).$$

The first and the second of these structures can be recognized as Kekulé's and the remaining three as Dewar's. The structure proposed by Claus, Ladenburg and others, can all be obtained from the above five by suitable combinations.

The number of such canonical structures becomes very large even for the simplest of condensed ring molecules. For example for naphthalene , the number of such structures is 42, and for the three-ringed molecules anthracene  and phenanthrene , the number is 429, and so on. If one has a partiality for any particular model, he can with a little diligence find his favourite in this list.

The Diamagnetism of the Mobile Electrons

One direct consequence of the freedom of the mobile electrons in benzene to migrate from atom to atom over the whole ring, would be an abnormal diamagnetism, confined to the direction perpendicular to the plane of the ring, because the diamagnetic moment is proportional to the area of the orbits described by the electrons under the influence of the magnetic field, and the mobile electrons can describe very much larger orbits in the plane of the benzene ring than the localized electrons. These diamagnetic effects should be even more marked in plane condensed ring compounds like naphthalene, anthracene, etc., in which the migrations of the mobile electrons can be more extensive. This explains the remarkable diamagnetic anisotropy exhibited by aromatic molecules. For example in benzene, the diamagnetic susceptibility along the normal to the plane of the molecule is nearly $2\frac{1}{2}$ times that along directions in the plane. Indeed the observed large diamagnetic anisotropies of these molecules offer the most striking evidence for the presence of the mobile electrons.

When such magnetically anisotropic molecules are arranged in a regular manner as in a crystal—in most organic crystals the molecules retain their individuality—the crystal as a whole will naturally exhibit an anisotropy, whose magnitude will depend on the anisotropy of the individual molecules and on their orientations relatively to one another. The closeness of approach of the molecules, which may not be the same along different directions in the crystal, will have practically no effect on the crystal anisotropy, since the diamagnetic moments induced in them will be too feeble to influence one another. In other words, the susceptibility of the crystal along any given direction will be merely the sum of the susceptibilities along this direction of all the constituent molecules.

When the magnetic constants of the molecule are already known, from measurements on the magnetic double-refraction of the substance in the liquid state or in state of solution in suitable solvents, magnetic studies on the crystal should enable us, in favourable cases, to obtain useful information about the orientations of the molecules in the crystal lattice. Such information will be very helpful in any structural analysis of the crystal by X-ray methods, since it may save much labour in the preliminary analysis, and will in any case offer an independent check on some of the results of the X-ray analysis.

This aspect of the magnetic studies on single crystals of aromatic compounds has been considered in detail elsewhere by Mrs. Lonsdale and the present writer, and I shall confine myself here to the converse aspect, namely that when the molecular orientations are already known from detailed X-ray studies, the crystal data enable us to calculate the principal

magnetic constants of the molecules, which interests us here. This is a more direct, and more accurate method for calculating the molecular magnetic constants, than the one based on measurements on the magnetic double-refraction in the liquid state, and besides is more general in its applicability.

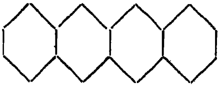
The Magnetic Anisotropies of Some Typical Aromatic Molecules

Extensive measurements have been made by Bhagavantam, Banerjee, Mrs. Lonsdale and the present writer on the magnetic properties of organic crystals, particularly of the aromatic class. For some of these crystals complete X-ray analyses have been made by Robertson and others, by the Fourier method. I give in the following Table the magnetic constants for some typical aromatic molecules, calculated from these data. K_1, K_2 and K_3 represent the three principal diamagnetic susceptibilities of the molecule, per gm. mol., and are expressed in the usual unit 10^{-6} c.g.s. e.m.u.; K_3 refers to the direction normal to the plane of the molecule; the directions of K_1 and K_2 in the plane of the molecule are as marked at the head of the Table. In those crystals in which the X-ray data are not sufficiently precise to enable us to calculate K_1 and K_2 separately, only one value is given in the Table, which will be a good approximation to either of them.

It will be seen from the Table that for all the molecules, the susceptibility along the normal to the molecular plane, namely K_3, is numerically much larger than either K_1 or K_2, in the plane, which are of comparable magnitudes. The difference, $\Delta K = K_3 - \frac{1}{2}(K_1 + K_2)$, which may be taken to be the contribution from the mobile electrons, wholly directed along the K_3 axis, is given in the last column of the Table; it is roughly proportional to the number of benzene rings in the molecule.

Optical Evidence for the Mobile Electrons in Aromatic Molecules

The restriction of the freedom of migration of the mobile electrons in these molecules to the molecular plane, is also evidenced by the striking directional variations in some of the optical properties of these molecules, observed some time ago by Mr. P. K. Seshan and the present writer. Let us take for example the plane condensed ring compounds naphthacene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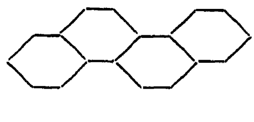
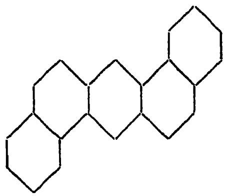
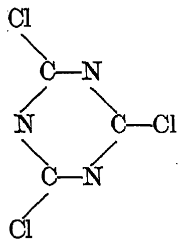

, 1, 2; 5, 6—

dibenzanthracene  , etc. They all have characteristic absorption and fluorescence bands in the visible region of the spectrum, which are presumably due to the transitions of the mobile electrons. It is found experimentally that it is only the component of the electric vector of the incident light-wave in the molecular plane which is absorbed by the molecule, whereas the component along the normal to the plane is not absorbed at all. In fluorescence also it is the component of the electric vector parallel to molecular plane which excites fluorescence, the perpendicular component being quite inactive. An elegant quantum-mechanical interpretation of these properties has recently been published by F. London.

Other Conjugated Molecules

Besides the benzene ring there are other plane ring structures which, on the conventional view, have alternate single and double bonds. Their diamagnetic properties should be very similar to those of the benzene ring, since they also must have mobile electrons which can migrate all over the ring. I shall mention here two such compounds, studied recently for their magnetic properties by Mrs. Lonsdale. One is cyanuric trichloride 

. The two principal susceptibilities of this molecule in the plane of the cyanuric ring are $-70{\cdot}9$ and $-71{\cdot}2$ respectively, whereas the third susceptibility, which is along the normal to the ring, is $-101{\cdot}3$, which is numerically much larger. The diamagnetic contribution from the mobile electrons is thus about -40, as compared with the value -54 of the mobile electrons in the benzene ring.

The second compound is metal-free phthalocyanine. The phthalocyanines are complex organic compounds, which are related to the natural porphyrins. They have been studied extensively by Linstead and his collaborators, and they have the formula $C_{32}H_{16}N_8M$, where M is a metal atom like Ni, Cu, etc.

The metal atom can be removed altogether, and the metal-free compound has the formula $C_{32}H_{18}N_8$. A complete X-ray analysis of the structure of this compound has been made recently by Robertson, and the molecule is found to have the following structure :—

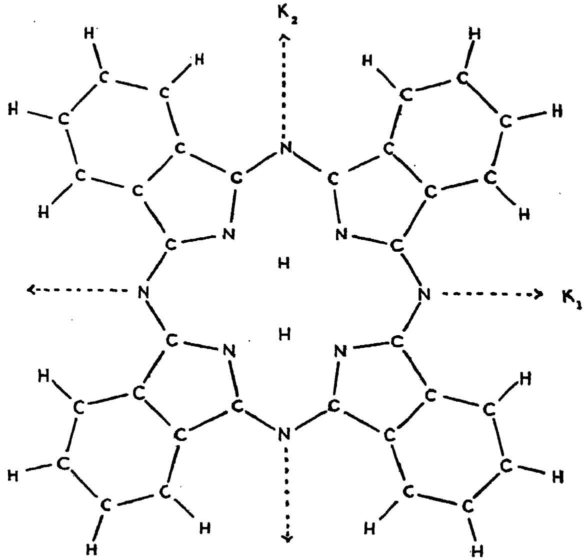


FIG. 4. Metal-free phthalocyanine molecule.

The most interesting part of this molecule, from our present point of view is the central zig-zag ring. It is a 16-membered ring of alternate carbon and nitrogen atoms, with two hydrogen atoms somewhere in the interior. This ring should exhibit resonance phenomena like the benzene and the cyanuric rings, and in view of its very large size, its diamagnetism along the normal to the plane of the ring should be enormous.

This is verified experimentally. The principal susceptibilities of the molecule are $K_1 = -120$, $K_2 = -165$, $K_3 = -982$. The susceptibility along the normal to the molecular plane is thus nearly 7 times that for directions in the plane. Even after allowing for the contributions from the outer rings, the contribution from the central 16-membered ring should be very large indeed, reminding one of the magnitudes involved in graphite.

Some Theoretical Considerations

Attempts have been made to calculate theoretically the magnitude of the diamagnetic anisotropy in some simple aromatic

molecules. Adopting a semi-classical theory—which we have adopted here in our description of the diamagnetic properties of the aromatic molecules—Pauling has evaluated the effective sizes of the orbits which the mobile electrons will describe in the plane of the molecule under the influence of a magnetic field incident perpendicular to the plane, and thence has calculated the contributions which these electrons will make to the diamagnetism. The values thus obtained agree roughly with the experimental values.

On this basis, for example, the large anisotropy of graphite would be attributed to the very large size of the orbits which the mobile electrons can describe in the basal plane, in the magnetic field. On this view any temperature-variation of the susceptibility is not contemplated, and indeed will be difficult to explain. But we found that experimentally the temperature-variation of the susceptibility is very marked in graphite, and also that this variation can be explained quantitatively on the quantum mechanical theory, as due to the change of the energy distribution of the electrons with temperature. To explain satisfactorily the diamagnetic behaviour of the mobile electrons in the aromatic molecules one has to adopt a similar method.

A quantum mechanical theory has been developed recently by London, and he has calculated the anisotropies of some simple aromatic molecules in terms of the anisotropy of the benzene molecule. His theoretical values are given in the following Table along with the experimental values for comparison :—

TABLE II

Molecule	$\frac{\Delta K}{\Delta K_{\text{benzene}}}$	
	Theoretical	Experimental
Naphthalene	2·19	2·11
Anthracene	3·45	3·39
Phenanthrene	3·19	3·07
Pyrene	4·46	4·11
Diphenyl	2·21	2·20

Attention may be drawn to one or two features in the experimental values, which are not obvious on Pauling's theory, but which follow from London's calculation: the anisotropy of diphenyl is found to be considerably larger than twice that of benzene; and there is a marked difference between the anisotropies of anthracene and phenanthrene.

It is interesting that experimentally the diamagnetic susceptibilities of the mobile electrons in chrysene, pyrene, and other condensed ring compounds do show an appreciable

temperature-variation. This variation, however, is much smaller than in graphite, suggesting that the kinetic energies of the mobile electrons in these molecules should be much larger than in graphite. This is indeed to be expected.

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SECTION OF PHYSICS

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SOME ASPECTS OF CRYSTAL MAGNETISM

1. Introduction.

Before 1912, many directional properties of crystals had been studied in detail. Thermal, optical, magnetic and electrical properties were known to vary with direction in noncubic crystals. Considerable evidence had been collected to show that crystals were composed of atoms and groups of atoms, arranged in a regular manner with respect to the points of a three dimensional space lattice. It was also recognized that the unit cell had dimensions of the order of a few angstroms.

The work of Laue and the Braggs showed that X-rays constitute a powerful tool in the study of crystal structure. X-ray methods have enabled us to study the interatomic distance in crystals, the nature of the structure, the electron density distribution in the unit cell and the character of the chemical bond in molecules. The entire field of organic chemistry has received considerable impetus by the application of X-rays in elucidating the structure of crystals.

In the study of metals and alloys, X-rays have played a significant part. Any structure which is proposed for a metal must satisfy the peculiar properties of metals like thermal and electrical conductivity, toughness and ductility. A few alloys are compounds of definite composition. But some others are solid solutions of varying concentration.

In certain cases, however, X-ray methods by themselves are unable uniquely to determine the structure of the crystal. As an aid, the known properties of the substance may be invoked. Magnetic properties of crystals are extremely useful in this matter. A knowledge of the principal susceptibilities of the individual molecules enables one to determine the alignment and orientation of the molecules in the crystal.

2. Ferromagnetic anisotropy.

From the point of view of applied magnetism, ferromagnetic property is the most important. Finished magnets and magnet parts are very much in demand in the radio and instrument-making industries. Special alloys like Alni, Alnico and Alcomax are used in the construction of these magnets. Magnetos, small motors and generators also employ permanent magnets, shaped to suitable design. In these cases, it is desirable

magnetic alloys and found that in Fe_2NiAl alloy, the special heat treatment gives a peculiar structure. The atomic distribution is no longer uniform throughout the crystal. Iron atoms form small islands without any sharp boundary, being held apart under conditions of great strain, thereby giving the alloy its remarkable magnetic properties[1]. The classical investigations on pyrrhotite and magnetite and later work on single crystals of iron, cobalt and nickel have revealed fruitful information regarding the origin of ferromagnetic anisotropy[2]. A full consideration of these aspects of crystal magnetism lies outside the scope of the present address.

3. Diamagnetic anisotropy.

The experimental wok of Curie laid the foundations of our present knowledge of magnetism. Langevin's expression for a spherically symmetric system

$$\chi_A = - \frac{e^2N}{6mc^2} \sum_Z \overline{r^2}$$

forms the basic equation in the study of diamagnetism. The summation, which is extended over the Z electrons in the atom, has been accomplished elegantly by Slater[3], whose treatment in certain respects was improved upon by Angus[4]. Since external factors do not have any large influence on diamagnetism, this property is additive. In fact, Pascal[5] showed that the susceptibility of a compound may be expressed as the sum of the susceptibilities of the constituent atoms, except for a factor of correction, whose value depends on the nature of the chemical bonds. Though many improvements have been suggested now and then, Langevin's theory still forms the basis of diamagnetic studies.

Raman and Krishnan[6] first suggested that ring-shaped aromatic molecules should have a large diamagnetic anisotropy. The first determination was carried out with naphthalene by Bhagavantam[7]. Subsequently Krishnan developed two important experimental methods of studying the principal susceptibilities of crystals and determined the values of several typical aromatic molecules[8].

Results of considerable interest on the relation between diamagnetism and crystal structure have been obtained with nitrates and carbonates. Krishnan and Raman[9] showed in 1927 that the anisotropy of crystalline nitrates and carbonates is due to the intrinsic anisotropy of the nitrate and carbonate groups. The CO_3 groups, for example, are arranged regularly parallel to each other in the crystal lattice with their planes perpendicular to the optic axis in calcite and normal to the c-axis in aragonite. These layers are interposed by layers of metallic ions. The large diamagnetic anisotropy which they worked out for the NO_3 group was fully substantiated by experiment with crystalline nitrates. The details of correlation were fully discussed by Krishnan, Guha and Banerjee[10], who determined directly the anisotropy for a few nitrates and carbonates. They found that the SO_4 group had negligible anisotropy, thus agreeing with the conclusions obtained from X-ray studies that the group has an approximate spherical

Nilakantan[11] found that the anisotropy of the CO_3 group in calcite ($\chi_\perp - \chi_\parallel = 3.89 \times 10^{-6}$) was smaller than that obtained with aragonite ($\chi_a - \chi_c = 4.86 \times 10^{-6}$). This difference has been attributed to a staggering of the CO_3 groups to one side in the (100) plane of the calcite crystal, a result obtained earlier by Bragg from X-ray data.

Krishnan and his collaborators and Lonsdale studied several organic crystals, including members of the triclinic, monoclinic, trigonal and orthorhombic classes. The mutual influence of neighbouring molecules in the solid state must be negligible. Lonsdale and Krishnan[12] have drawn attention to the fact that since the molecules are themselves anisotropic, the principal crystal susceptibilities are determined by tensor additions of the susceptibilities of the individual molecules comprising the given crystal.

Let K_1, K_2 and K_3 be the principal molecule susceptibilities and $(\chi_1)_M$, $(\chi_2)_M$ and $(\chi_3)_M$ the principal crystal susceptibilities per gram molecule.

$$(\chi_1)_M = K_1 \cos^2 \alpha_1 + K_2 \cos^2 \beta_1 + K_3 \cos^2 \gamma_1$$

$$(\chi_2)_M = K_1 \cos^2 \alpha_2 + K_2 \cos^2 \beta_2 + K_3 \cos^2 \gamma_2$$

$$(\chi_3)_M = K_1 \cos^2 \alpha_3 + K_2 \cos^2 \beta_3 + K_3 \cos^2 \gamma_3$$

Here α_1, α_2 and α_3 are the angles made by the K_1 direction with the directions of $(\chi_1)_M$, $(\chi_2)_M$ and $(\chi_3)_M$, etc.

In the case of triclinic crystals, the principal molecule susceptibilities coincide with the directions of $(\chi_1)_M$, $(\chi_2)_M$ and $(\chi_3)_M$. We get directly the values of K_1, K_2, and K_3. The outstanding example is hexamethyl benzene for which $K_1 = -$ 011.1, $K_2 = -$102.1, $K_3 = -$ 163.8 in 10^{-6} unit. The aliphatic carbons are in the plane of the benzene ring, there being almost perfect symmetry.

As the crystal symmetry improves, molecular orientations become difficult to determine. In cubic crystals, the arrangement of anisotropic molecules is such that the anisotropies will mutually cancel out. No information regarding molecular orientation becomes possible.

The aromatic compounds show really striking anisotropy. Perhaps the largest anisotropy is shown by metal-free phthalocyanine ($C_{32} N_8 H_{18}$) for which $K_1 = -$ 165, $K_2 = -$ 120 and $K_3 = -$ 982 in 10^{-6} unit. It is not possible to detail here the cases where the crystal structure has been worked out purely from magnetic data or where magnetic evidence has helped to choose between alternative structures.

Calculations on theoretical grounds of the anisotropy of some aromatics have been made by Pauling[13], Lonsdale[14] and London[15]. Pauling's conclusions show that in the case of benzene, six L electrons which are responsible for resonance in the structure may be considered to be free to move from one carbon to another in a magnetic field, thus describing orbits

results and explained in a systematic manner the observed anisotropy of several ring compounds.

4. Paramagnetic anisotropy.

For substances whose molecules possess a permanent magnetic moment, the classical treatment of Langevin and Weiss[16] gives for the gram molecular susceptibility the expression $X_M = C_M / (T - \theta)$. Here θ is the Curie temperature and $C_M = \sigma_o^2 / 3R$, where σ_o is the saturation magnetic moment per gram molecule. Hence $\sigma_o = \sqrt{3R\chi_M (T - \theta)}$. The value of σ_o is usually expressed in terms of the Bohr magneton, whose value is 5564.

$$\text{Hence } p_B = \sigma_o / 5564 = \frac{\sqrt{3R}}{5564}\sqrt{\chi_M (T-\theta)} = 2.839\sqrt{\chi_M (T-\theta)}$$

Sometimes the magneton value is given on the assumption that the Curie law is valid.

$$p_B \text{ (effective)} = 2.839\sqrt{\chi_M T}$$

The magneton values of simple ions were first deduced from spectroscopic data by Hund[17], who obtained $p_B = g\sqrt{j(j+1)}$ where g is the Lande factor. This formula is found to hold good for the rare earth ions, for which the multiplet interval is large compared with kT. For ions in the S-state, this reduces to $p_B = \sqrt{4s(s+1)}$. When $h\nu << kT$, it has been shown that $p_B = \sqrt{l(l+1) + 4s(s+1)}$.

Stoner[18] showed that in the case of the rare earth ions, the magnetically effective electrons, belonging to the $4f$ group, are screened from external interaction by a complete group of higher total quantum number. But in the ions of the first transition series, the incomplete group, namely the $3d$ group, is also the outermost. Hence due to interaction between neighbouring ions, the l moment becomes partly or wholly ineffective. Data obtained for ions of the first transition series show definitely that in the solid state, there exist interaction effects which leave the spin free but partially or completely quench the effect of the orbital moment. These considerations go to show that the magnetic moments of the rare earth ions obey the Hund rule while those of the first transition series are given by $p_B = \sqrt{4s(s+1)}$.

We owe much of our knowledge relating to the theoretical aspects of crystalline fields to Van Vleck[19], Schlapp and Penney[20]. The internal electrical fields may be so feeble that the coupling between the orbital and spin moments remains practically unaffected, as in the case of the rare earth salts mentioned above. The effect of the internal fields will be to produce a slight Stark effect on the lowest level. This results in a redistribution of the magnetic moment, which affects the temperature dependence of the susceptibility, particularly at low temperatures.

When the fields are sufficiently strong, the spin orbital coupling breaks down but the Russell-Saunders coupling remains unaffected. The degeneracy with respect to orbital moments would have been removed by the crystalline fields. If $h\nu >> kT$, the introduction of the magnetic field would not alter the distribution of the ions among the levels and there will be no contribution from the orbital moments to the effective magnetic

moments of the ions. Since the spin moments are not affected directly by crystalline fields, the susceptibility will be due to spin only, as in the case of the sulphates and selenates of the iron group of elements.

If the crystalline fields are not symmetrical, the crystal must show definite directional properties. In such cases, the crystal evinces magnetic anisotropy. If the surroundings of the ions have cubic symmetry, the potential field may be represented by D $(x^4 + y^4 + z^4)$. For rhombic symmetry, the lowest terms that can occur are $Ax^2 + By^2 + Cz^2$. Fields of monoclinic and triclinic character may be represented by superposing a cubic and a rhombic part with different axes.

The presence of the internal crystalline fields is definitely indicated by the fact that in such cases, the Curie-Weiss law $\chi_M = C_M / (T - \theta)$ and not the Curie law is obeyed. A large value of θ generally indicates the presence of a large internal field. That a small value of θ does not necessarily imply a weak field is shown by the results of Krishnan and Mukerji[21] obtained with copper sulphate crystals. They have found the effective magnetic moments of the Cu $(H_2O)_4^{++}$ complex to be 2.12 Bohr magnetons when the magnetic field is normal to the plane of the complex and 1.80 when the field is in the plane.

On these ideas, crystals containing paramagnetic ions in the S-state should not show any magnetic anisotropy. This is found to be the case with manganous and ferric salts in which Mn^{+2} and Fe^{+3} ions are in the S-ground state[22]. The three principal susceptibilities of crystals containing these ions do not differ by more than 1 per cent. Krishnan and Banerji[23] found that in the case of rhodochrosite $(MnCO_3)$, the equation $\chi_M = C / (T + 13)$ was obeyed, with the effective Bohr magneton value to be 5.56. The Stark separation produced by the crystalline field was only 0.07 $cm.^{-1}$.

Measurements of the principal susceptibilities of paramagnetic crystals were initially made by Rabi[24], Jackson[25] and Bartlett[26]. The accurate investigations of Krishnan and his collaborators, employing the critical torsion method, have yielded results of importance and enabled us to understand correctly the phenomenon of crystal paramagnetism.

5. Metallic single crystals.

Modern structural chemistry is based on the nature of the chemical bond. The three extreme types of chemical bonds are electrostatic, covalent and metallic bonds. In the metallic linkage, the ions are held together by the mobility of the bonding electrons. The susceptibility of the metal is the algebraic sum of the susceptibilities of the positive ions and of the free electrons. These electrons evince a small temperature-independent paramagnetism, whose value has been worked out by Pauli[27]. In metals at ordinary temperatures, there is also the Landau[28] diamagnetism, which in magnitude is one-third of the Pauli paramagnetism. The susceptibility per gram atom of the metal is given by $(\chi_A) = (\chi_A)_{\text{ion}} + (\chi_A)_{\text{electron}}$ where $(\chi_A)_{\text{electron}} = (32.1\ q / V_O) \times 10^{-6}$. Here q is the number of free electrons per atom and V_O the width of the energy band occupied by the electrons. The values of V_O obtained for the alkali elements are smaller

than the values calculated for perfectly free electrons on quantum mechanical grounds. This difference is attributed to a narrowing of the energy bands of the free electrons in the alkali elements.

Single metal crystals may be prepared after Bridgman by the method of slow cooling. They are ordinarily obtained in the shape of rods, about 10 to 12 cm. long and 4 to 5 mm. diameter. Any specimen is suspended with its axis vertical and the lower end symmetrically between the pole pieces of an electromagnet arranged to give a uniform field. The Gouy force on the rod is determined in different positions as it is rotated about its axis through 360°. The angle between the axis of the cylinder and the principal axis of the crystal may be directly determined in crystals like bismuth which break easily. In other cases, $\chi_{\perp}$ and $\chi_{\parallel}$ are determined from a further knowledge of the susceptibility of the polycrystalline metal.

Bismuth crystals have been studied by Goetz and Focke[29] and by Schoenberg and Uddin. Goetz and Focke showed that the value of $\chi_{\perp} / \chi_{\parallel}$ increases on dissolving small quantities of tin and lead and decreases on adding tellurium and selenium. The magnetic anisotropy thus increases when the dissolved metal is electropositive with respect to bismuth and decreases when electronegative. Schoenberg and Uddin report that $\chi_{\parallel} / \chi_{\perp}$ is not a linar function of temperature. These conclusions have been accounted for by Jones[31] from considerations of the Brilliouin zones in the bismuth crystals. John[32] and Rao[33] have also investigated bismuth crystals by Krishnan's method of critical torsion.

Thallium crystals were studied by Rao and Subramaniam[34]. At room temperature, this metal exists as α -thallium crystallizing in the hexagonal close-packed structure. The principal susceptibilities are $\chi_{\parallel} = -0.412 \times 10^{-6}$ and $\chi_{\perp} = -0.165 \times 10^{-6}$. The anisotropy $\chi_{\perp} / \chi_{\parallel}$ is smaller than the corresponding value for other metals with the exception of antimony. On heating, α -thallium passes into the β -variety at 235°C., the structure of this form being cubic. The mean mass susceptibility decreases from -0.247×10^{-6} to -0.158×10^{-6} as the crystal is heated from room temperature to values over 235°C. At the melting point, the value falls further to -0.131×10^{-6}. These results show that in α -thallium, two of the three valence electrons have their orbits in the hexagonal plane and that their binding is homopolar. The third electron is considered free. In the β -thallium, which has a face-centred cubic lattice, we have Tl^{+1} ions with the single valence electron showing a metallic linkage. These considerations fully account for the observed magnetic properties of thallium crystal.

Rao and Narayanaswamy[35] studied the influence of small admixtures of cadmium, lead, tin and bismuth. They concluded that the decrease in the anisotropy of thallium was not entirely dependent on the number of valence electrons per atom of the metal introduced.

Cadmium crystals were studied by Rao and Sriraman[36]. The magnetic anisotropy ($\chi_{\parallel} / \chi_{\perp}$) 1.368 was nearer the value for zinc than the result obtained earlier by MacLennan, Ruedy and Cohen[37]. Traces of zinc do not alter the principal susceptibilities of cadmium but lead changes the value of $\chi_{\perp}$ leaving $\chi_{\parallel}$ unaffected. The valence electrons appear to

contribute a greater paramagnetic component normal to the c-axis than parallel to it. Evidence from electrical conductivity data support the conclusion.

The effect of stress on a metal in which the binding is metallic has been examined by Honda and Shimizu[38], who find that cold working causes a small increase in the diamagnetic susceptibility. Rao[39] studied the effect of cold working on metals and found full support for the theory proposed by these authors. The experiments incidentally show the great influence exercised by the boundaries between the small crystals in a polycrystalline metal on its physical properties.

Among other metal crystals studied are those of tin by Hoge and Rao[41], antimony by Hart[42] and mercury by Vogt[43]. Magnetic evidence proves interesting in the case of mercury at room temperature. The atomic susceptibility of mercury (which is in the $^1S_0$ state) works to -84.6×10^{-6} on the calculations of Slater and Angus. Shur[44] found the value for mercury vapour to be -78×10^{-6}. Mercury vapour is thus shown to be monoatomic. For purified and distilled mercury, Bhatnagar and Nevgi[45] obtained -31.5×10^{-6}, Bates [46] obtained -33.6×10^{-6} and Rao and Aravamudachari[47] -33.3×10^{-6}. These values are close to -37×10^{-6}, the value calculated for Hg^{+2}. These and other considerations show that a close-packed structure persists in liquid mercury. The two valence electrons are free, thus giving the metal a large electrical conductivity.

6. Nonmetallic single crystals.

While there has accumulated a large amount of information on the magnetic anisotropy of metal crystals, information regarding nonmetals is scanty. Iodine crystals were studied by Rao and Venkataramiah[48]. Iodine crystallizes in the orthorhombic system. Cleavage takes place easily along the *ac*-plane. Iodine (I_2) is found to have a value -98.75×10^{-6} per gram molecule parallel to the axis of the molecule and -84.03×10^{-6} normal to the axis. The axis of the molecule makes an angle of 51° with the direction of the *a*-axis.

Rao and Govindarajan[49] investigated single crystals of tellurium. The principal susceptibilities parallel and perpendicular to the trigonal axis are found to be -42.0×10^{-6} and -37.8×10^{-6} per gram atom. These results show that the linkages are not metallic. From the magnetic point of view, tellurium behaves like a nonmetal. The specific resistance obtained by Bridgman is also very high. On introducing small quantities of tin, cadmium, bismuth and lead, it is found that the decrease in anisotropy depends completely on the atomic radius of the element introduced and not on the number of valence electrons in the element.

The principal susceptibilities of rhombic sulphur have been determined by Krishnan, Guha and Banerjee and later by Nilakantan[50]. Nilakantan reports that magnetic analysis shows that the plane of the S_8 molecule makes an angle of 71° with the *a*-axis.

The magnetic properties of diamond and graphite are of great interest. The gram atomic susceptibility of diamond is about -5.8×10^{-6}. Graphite crystallizes in the hexagonal system. It consists of hexagonal layers of molecules. The bonds in the layer molecules are trigonally

arranged and are 1.431 A in length. The distance between the layers is 3.42 A which is so large that there cannot be any covalent layer between them. The layer molecules are held together by weak forces of the van der Waals type. The chemist's picture would suggest that while three of the four valences of the carbon atom are used to form bonds with its three neighbours, the fourth resonates amongst the three, giving for each carbon-carbon bond one-third double bond character.

This picture gets a satisfactory explanation by the application of magnetism. The large diamagnetism of graphite along the hexagonal axis is well known. Sir C. V. Raman[51] explained that this might be due to large electronic orbits in the basal plane. Krishnan and his collaborators found that at room temperature, the specific susceptibility normal to the hexagonal axis is -0.5×10^{-6} and the value parallel to the axis -24.7×10^{-6}. The value $\chi_{\|} - \chi_{\perp}$ was studied at different temperatures ranging from 90°K. to 1270°K. As the temperature is raised, the anisotropy is found to vary rapidly at first and then more gradually, the end values being -28.8×10^{-6} and -7.8×10^{-6}. From these data, Ganguli and Krishnan[52] have drawn some extremely interesting conclusions.

The number of free electrons in graphite is one per carbon atom. Movements of these electrons in the basal plane are completely free but they cannot jump from any plane to the next. This tight binding accounts for the low degeneracy temperature of 520°K. Over the large range of temperature investigated, the free electron diamagnetism is found to be wholly the Landau diamagnetism of the free electron gas obeying Fermi-Dirac statistics. Causes are adduced to show that the spin paramagnetism of the free electrons is practically absent. The low degeneracy temperature of 520°K. of the free electrons in graphite makes it a very convenient medium for studying the properties of an electron gas. The picture fits well with the chemist's idea of the electronic structure of graphite.

On treating graphite crystals with a mixture of concentrated sulphuric acid and nitric acid, "blue graphite" is formed. Ganguli[53] found that this treatment reduces the anisotropy to the same order of magnitude as in aromatic molecules containing several condensed benzene nuclei, that is, 1.3×10^{-6} per gram content of carbon. The large diamagnetism along the hexagonal axis is destroyed while the value in the basal plane remains unaffected. This variation obviously shows that the metallic linkage responsible for the large diamagnetism breaks up on treatment with the acid.

7. The colour of minerals.

We shall now consider certain special lines of study in paramagnetism.

A fascinating part of the study of minerals is the problem of colour. As is well known, they display an infinite variety of colour. Organic dyes have been known to produce a considerable range of colours, but these shades show a tendency to fade away in daylight. Some topazes from Siberia have been known to lose their brown colour on exposure to strong sunlight, presumably because the colour is due to organic dyes. Some gemstones when exposed to X-rays or radioactive rays acquire a colour.

Diamond, for example, becomes bluish green or violet. The colour, however disappears on heating.

The colours of most gemstones are due to the admixture of some inorganic materials, presumably metallic oxides. These agents give a permanence of colour. Sometimes the colouring matter may be an essential constituent of the chemical composition of the mineral or it may be extraneous to it. These agents may be present in such small quantities that chemical analysis may not show their presence. Absorption spectra may yield better results but when two or more agents are present, the cause of the colour becomes ambiguous.

It is of interest to note that most of the colouring agents are paramagnetic. Iron, both in the ferrous and ferric state, chromium, titanium and manganese are responsible for the colour of many minerals. Equally effective are vanadium, cobalt and nickel. It may be easily seen that ions of these metals are all paramagnetic. A magnetic study of these minerals is likely to be of advantage.

A typical example of the effectiveness of the application of magnetism to the problem of colour is amethyst. The purest varieties of quartz are colourless. The low temperature form known as α-quartz is hexagonal with three molecules of SiO_2 in the unit prism[54]. Each silicon atom is surrounded by a distorted tetrahedron of oxygen atoms. The distance between Si^{+4} and O^{-2} centres of the same molecule is 1.631 A and of adjacent molecules 2.176 A. The crystal is composed of three interpenetrating simple triangular lattice. The unit triangle in each basal plane is rotated through 120° with respect to the next one. A careful determination of the magnetic susceptibility of a few crystals showed that the anisotropy was feeble. Cady[55] gives 4.5 for the dielectric constant of quartz perpendicular to the optic axis and 4.6 as the value parallel to the optic axis, the anisotropy here being negligible.

Recently a detailed investigation of the magnetic properties of amethyst quartz was carried out in Central College, Bangalore, by Leela. Two specimens of amethyst were available, one from Jubbulpur (the origin probably being Madhya Pradesh) and the other from Sir C. V. Raman's collection of minerals. The Madhya Pradesh variety had a uniform beautiful violet colour. Crystals of amethyst and colourless quartz were formed on the same cluster. It was instructive to compare the mean susceptibilities of the colourless and the coloured specimens. There was no evidence of any free ferromagnetic impurity. The specific gravity and the mean magnetic susceptibility of colourless quartz were 2.653 and -0.40×10^{-6} respectively. Those of amethyst were 2.655 and -0.33×10^{-6}. The colour is obviously due to a paramagnetic impurity which contributes $+0.07 \times 10^{-6}$ per gram of the specimen. Several crystals from Sir C. V. Raman's collection were similarly studied. Each crystal had three portions. One portion was colourless ; another had a uniform amethyst colour and the third portion was somewhat dark and not uniform. Experiments showed that the first portions gave for the mean mass susceptibility -0.33×10^{-6} and the second -0.20×10^{-6}. The third portions gave varying values from $+0.05 \times 10^{-6}$ to $+0.38 \times 10^{-6}$. The tinctorial agent is definitely paramagnetic.

It is well known that when amethyst is heated, the colour begins to

disappear at about 260°C. A few crystals were baked at 450°C. for about 2 hours. Some crystals showed a tendency to form cracks. Almost all the crystals showed a slight yellowish tinge after the heat treatment. When the susceptibility was redetermined later, the diamagnetic value increased slightly but the value was still far below that of the colourless quartz.

These results preclude the possibility of the colour being due to organic dyes. The possibility of manganese causing the colour is unlikely because crystals, which do not show any traces of manganese are known to be coloured. The twinning of right-handed and left-handed quartz has sometimes been mentioned as the cause of the colour in amethyst. That will not explain the magnetic observations outlined above. The magnetic evidence seems to indicate that the colour may be due to ferric iron, existing as ferric hydroxide or a mixture of ferric hydroxide and ferric oxide. On heating the crystal, the resulting product is the stable ferrous oxide. This produces a small decrease in the paramagnetic contribution of the impurity and hence the diamagnetic susceptibility of the crystal shows a small increase. In the case of all the amethyst crystals heated to about 4.50°C., Leela found that there was a small but definite loss of weight, due presumably to the loss of water from the hydroxide.

In support of these conclusions, it may be mentioned that Herbert Smith[56] states that a study of the absorption spectra suggests that iron in a colloidal form may be responsible for the colour of amethyst. Holden ascribes the colour to hydrated ferric oxide.

It is of interest to compare the calculated and observed values for the susceptibility of quartz. In this crystal, silicon and oxygen exist as Si^{+4} and O^{-2} ions. A molecule SiO_2 has a real existence and the crystal is a molecular crystal. Angus gives for the susceptibility of the Si^{+4} and O^{-2} ions, the values -1.87×10^{-6} and -11.25×10^{-6} respectively per gram ion. The value for SiO_2 works to -24.37×10^{-6} per gram molecule and -0.41×10^{-6} per gram. The latter value agrees with -0.40×10^{-6} obtained with some good crystals from Madhya Pradesh.

Tourmaline displays a variety of colour. An approximate formula is (Mg, Fe, Mn, Ca, Na, K, Li, H) $Al_3\ B_2\ Si_4\ O_{21}$ with isomorphous replacements of the several elements bracketed together. The crystal is rhombohedral in structure. Lithium tourmalines are rose coloured, magnesium tourmalines are brown and iron tourmalines are deep black. Green crystals containing chromium are also found. One would expect, therefore, a wide difference in the magnetic properties of these crystals, one set, with iron and chromium, showing a large paramagnetic value and the other, with lithium and magnesium, having a small susceptibility. Of the former group, the iron tourmalines containing the Fe^{+2} ion would show a large paramagnetism and a large anisotropy, while the chromium tourmalines containing Cr^{+3} would show a large paramagnetism and a small anisotropy. These different classifications are well realized in the results of Sigamony[57] on the magnetic properties of a few specimens of tourmaline. It is obvious from the small paramagnetism obtained with Li and Mg tourmalines that the colours should be due to the presence of paramagnetic traces of elements of the first transition series. Some dark crystals, studied in Central College, gave large values for the paramagnetic

susceptibility, one set giving about 16 $\times$ 10^{-6} (specific gravity = 3.08) and the other set about 25 $\times$ 10^{-6} (specific gravity = 3.17).

8. Magnetic study of silicates.

The silicates comprise a large proportion of the earth's crust. They show a wide range in chemical composition. Some of them are very complex in character. Chemical methods alone are not enough to solve their problems, since most of them are solids and the nature of the constituent groups is completely lost in this state. The structure of these substances has been elucidated with remarkable success, primarily by the labours of W. L. Bragg and Pauling[58].

The fundamental structural unit is the SiO_4 group which is tetrahedral, with four oxygens around the silicon. These groups are lined together in various ways, with one or more oxygens, common to neighbouring groups. We thus have the pyroxenes, corresponding to SiO_3, the amphiboles to Si_4O_{11} and the micas to Si_2O_5. In all these cases, the structures are divided into chain, band and sheet structures. If three-dimensional networks be formed, the tetrahedra are linked by all three corners. Quartz is one of such forms.

A magnetic study of the different structures of silicates will be of special interest. Attention may here be drawn to the work of Nilakantan[59] on some micas and the results he has obtained fully justify the study of silicates from the magnetic point of view. He studied the mean susceptibility and anisotropy of specimens of muscovite, phlogotite and biotite. The biotites were from Canada, the Ural mountains and Bihar. They contained different proportions of iron. The susceptibility and anisotropy were found to depend on the amount of iron present. Muscovite and phlogotite, containing only 3.93 and 4.34 per cent of iron gave specific susceptibilities of 8.01 $\times$ 10^{-6} and 7.85 $\times$ 10^{-6} and anisotropy $(\chi_{\parallel} - \chi_{\perp})$ of 0.65 $\times$ 10^{-6} and 1.38 $\times$ 10^{-6} respectively. In all cases, the mean susceptibility varied linearly with the iron content. Considering the total iron present, the effective Bohr magneton value obtained with the biotites (containing 15.2 to 23.1 per cent of iron) was about 5.0 which is near 4.90, the spin value of Fe^{+2} ion.

The anisotropy, however varied linearly with the ferrous iron content, the ferric iron contributing a negligible anisotropy. This is presumably due to the interactions between neighbouring iron atoms. The structure of mica is favourable for such interactions to take place, since the iron atoms lie in the same plane and their population is high enough in biotites for them to occupy adjacent positions of six co-ordination.

Further work on the susceptibilities of silicates showing typical structures will no doubt be useful from different points of view.

9. Pleochroism.

In certain coloured uniaxial crystals, the ordinary and extraordinary rays emerge from the section with distinctly different colours. This is obviously due to the differential absorption of the rays. When, for example, a thin section of brown tourmaline cut parallel to the optic axis is observed

in plane polarized light, the colours are dark brown and light brown in two mutually perpendicular positions of the crystal. The ordinary rays are absorbed much more than the extraordinary rays. That accounts for the difference in colour obtained. In biaxial crystals, there may be in general three different degrees of absorption corresponding to the three different directions of vibration lying at right angles to each other. Due to this selective absorption, the crystal may show different colours when viewed in different directions. The crystal is then said to exhibit the property of pleochroism.

Evidence collected from various minerals goes to show that strongly paramagnetic bodies exhibit pleochroism. Crystals rich in iron show this property in a remarkable manner. Magnetic anisotropy and pleochroism do not have any correlation. Some crystals like rose tourmaline, which have a feeble magnetic anistropy, show pronounced pleochroism. Nilakantan has drawn attention to the fact that magnetic anisotropy is indicated by the ground state of the paramagnetic ion. But when these ions absorb radiation, the higher energy states may experience a large Stark effect in the crystalline fields and this may result in asymmetric splitting and pleochroism. Obviously pleochroism must be strongly marked when both the ground state and the higher state are strongly affected by the crystalline fields.

The mechanism of the absorption of light has been considered by Saha[60]. Colours are almost entirely shown by the compounds of the transitional group of elements. Considering a substance like $CrCl_3$, the colour is due to the Cr^{+3} ion. The consequent absorption of light in the visible region is due to some of the 3d electrons changing their spin vector from $+ 1/2$ to $- 1/2$. Such a transition will apparently be permissible in cases where the orbital moment gets quenched and the spin moment is predominant. That may explain why salts which show a large magnetic anisotropy due to asymmetric crystalline fields also exhibit strong pleochroism.

These considerations were applied to the case of biotites by Nilakantan. The paramagnetic susceptibility parallel to the cleavage plane is much greater than that perpendicular to it. Hence for light waves with the electric vector parallel to the cleavage plane, the response of the spins to get reversed is more favourable. The reversal of the spin vector takes place in the cleavage plane and not perpendicular to it. Pleochroism of the biotites thus finds a natural explanation.

In this connection, the work of Krishnan and Chakrabarthy[61] is interesting. They studied the polarization of the absorption lines of single crystals of the hydrated sulphates of praseodymium and neodymium (Pr and Nd). Many of the lines were found to be strongly polarized, some of them being confined to vibrations along one or another of the principal axes of the optical ellipsoid of the crystal. Such variations were found to occur even among the Stark components originating from the same absorption line of the free ion. The crystalline electric fields, producing the Stark splitting, are highly anisotropic and the crystals show strong magnetic anisotropy.

A large amount of information is available on the pleochroic properties of different minerals. The characteristics of some crystals like

biotite and tourmaline containing different percentages of iron are generally understood. But a detailed examination of their magnetic anisotropy and polarization behaviour of the absorption lines is necessary before a strict approach to these problems becomes possible.

10. Magnetism and valency.

It often happens that, under suitable conditions, the chemical bond changes in type continuously from the extreme covalent structure to the extreme ionic structure. At any intermediate stage, the bond is described as resonating between the extremes, the percentage contribution of each being ascertainable. The actual energy consideration of the bonds settle this ratio, depending on the stability of the molecule. This type of resonance is possible only when the two structures involve the same number of unpaired electrons. If, however, the two structures involve different numbers of unpaired electrons, the transition between the two must be discontinuous.

As an example, consider the octapedral complex FeX_6 of ferric iron. Pauling[62] has shown that when the Fe-X bonds are ionic, 5 electrons occupy the five 3d orbitals without pairing. If the Fe-X bonds are covalent, the five electrons occupy the remaining 3d orbitals, resulting in the formation of two pairs and one unpaired electron. Transitions between these structures are therefore discontinuous. In the former case, the magnetic moment of the ferric iron is 5.92 and in the latter case 1.73 Bohr magnetons. It may be shown similarly that in the case of the Fe^{+2} ion, the magnetic moment is 4.90 Bohr magnetons when the linkage is ionic and O when the linkage is covalent. From magnetic criteria, therefore, it should be possible to determine the nature of the bond in these cases.

It is of interest to examine the properties of iron pyrites FeS_2. The crystal structure of pyrites was studied by W. L. Bragg. It crystallizes in the cubic form, the lattice constant a being 5.11 A. The iron atoms lie on a face-centred cubic lattice and the sulphur atoms lie on the trigonal axes of this cubic frame work, associated in pairs with the unoccupied cube corners. Each sulphur atom is surrounded tetrahedrally by three iron atoms and one sulphur atom. Each iron atom is surrounded by six sulphur atoms, which lie at the corners of a nearly regular octahedron. The Fe-S distance is 2.27 A and the S-S distance 2.10 A.

Jackson[63] showed from magnetic data that the ferrous iron in pyrites is like what obtains in the ferrocyanide ion and not what it is in ferrous sulphate. Parker and Whitehouse [64], from X-ray investigations suggest that the pyrites structure is based on homopolar binding. The low paramagnetic suspectibility of pyrites crystals shows that the bond must be essentially covalent, having a feeble ionic linkage.

However, the experiments of Sigamony[65] and Ramaseshan[66] show the existence of pyrites crystals having relatively large values of specific paramagnetic susceptibility. Ramaseshan found that as the specific gravity falls from 5.001 to 4.919, the magnetic susceptibility increases from 0.247×10^{-6} to 289×10^{-6}. He has drawn attention to the work of Juza and Blitz who prepared chemically sulphides of iron. When the specific gravity decreases from 4.975 to 4.593, the magnetic susceptibility increases

from 0.45×10^{-6} to 5590×10^{-6}. The substance initially FeS_2 becomes a mixture of FeS_2 and FeS and finally FeS.

Fine iron pyrites crystals sufficiently small for magnetic investigations were available from the Lakkavalli area in Mysore State. Over sixty crystals were studied by Leela in Central College. Most of the crystals had values ranging from 100×10^{-6} to 400×10^{-6}, the crystals with larger values showing relatively larger ferromagnetic impurity. On plotting specific gravity against paramagnetic susceptibility, a variation of the type observed by Ramaseshan was obtained. But instead of one curve, two different curves were obtained, one group having a susceptibility near 100×10^{-6} and the other group, a more prominent one, having values ranging from 200×10^{-6} to 400×10^{-6}. In each group, the susceptibility increases as the density decreases from 5.04 to 4.65.

A few crystals from the Cuddapah area gave very low paramagnetism (0.2×10^{-6} to 0.4×10^{-6}). Yet they showed a similar variation between specific gravity and paramagnetic susceptibility. These results show that for the same specific gravity, it is possible to have different values of the specific susceptibility, depending on the group to which the crystals belong.

Observations show that the crystals had no free magnetic moment. The paramagnetic susceptibility shows a small decrease with increase of temperature. Crystals with relatively larger paramagnetism show a greater electrical conductivity.

Part of the variation may be attributed to a partial change in the bond type from a covalent to an ionic one. It has already been stated that the ferrous ion has the value 4.90 Bohr magnetons when the bond is ionic and O when it is covalent. But this by itself cannot explain the large changes observed. It is obvious that the decrease in density must be due to a decrease in the number of sulphur atoms present. These results confirm the observations of Juza and Blitz but the causes for the large paramagnetism of ferrous sulphide are not clear.

The possible valency of manganese in manganite crystal has been worked out from the magnetic point of view by Krishnan and Banerjee[67]. The chemical composition of the mineral is Mn_2O_3, H_2O. It crystallizes in the monoclinic system according to Buerger, though later workers assign an orthorhombic system. Krishnan and Banerjee find that $\chi_c - \chi_a = 4.0 \times 10^{-6}$ and $\chi_c - \chi_b = 3.0 \times 10^{-6}$ per gram atom of Mn. They have shown that if the manganese is trivalent, the ground state of Mn^{+3} is $^5D_0$ That should give rise to a large anisotropy as evidenced by manganic acetylacetone at 31°C., which has an anisotropy of 75×10^{-6} per gram ion of Mn^{+3}. On the other hand, Mn^{+2}. (ground state $^6S_{5/2}$) and Mn^{+4} (ground state $^4F_{3/2}$) are not expected to show such a large anisotropy. The fact that the observed anisotropy of the manganite crystal is small shows that Mn atoms are not trivalent. Presumably half of them are divalent and the other half tetravalent.

Conclusion.

It is hoped that this general survey of crystal magnetism would focus attention on the importance of this branch of study. A large amount

of experimental work in different directions is still necessary in order that many problems, connected directly or indirectly with the magnetic properties of crystals, may receive a satisfactory solution.

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